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PB-295 227

Symposium on the Transfer and Utilization of Particulate Control Technology: Volume 2 Fabric Filters and Current Trends in Control Equipment

Denver Research Inst., CO

Prepared for

Industrial Environmental Research Lab., Research Triangle Park, NC

Feb 79

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-79-044b	2.	3. RECIPIENT'S ACCESSION NO. PB295227
4. TITLE AND SUBTITLE Symposium on the Transfer and Utilization of Particulate Control Technology: Vol. 2. Fabric Filters and Current Trends in Control Equipment		5. REPORT DATE February 1979 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) F.P. Venditti, J.A. Armstrong, and Michael Durham		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Denver Research Institute P.O. Box 10127 Denver, Colorado 80208		10. PROGRAM ELEMENT NO. EHE624 11. CONTRACT/GRANT NO. Grant R805725
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Proceedings: 10/77-10/78 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Dennis C. Drehmel, Mail Drop 61, 919/541-2925.

— during the Symposium!

16. ABSTRACT

Papers in the proceedings were presented at the Symposium on the Transfer and Utilization of Particulate Control Technology, in Denver, Colorado, July 24 through 28, 1978. The symposium was sponsored by the Particulate Technology Branch of EPA's Industrial Environmental Research Laboratory--Research Triangle Park, and was hosted by the University of Denver's Denver Research Institute. The symposium brought together researchers, manufacturers, users, government agencies, educators, and students to discuss new technology and to provide an effective means for the transfer of this technology out of the laboratories and into the hands of the users. The three major categories of control technologies--electrostatic precipitators, scrubbers, and fabric filters--were of major concern. These technologies were discussed from the perspectives of economics; new technical advances in science and engineering; and applications. Several papers dealt with combinations of devices and technologies, leading to a concept of using a systems approach to particulate control, rather than device control.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Fabrics	Pollution Control	13B	11E
Dust	Economics	Stationary Sources	11G	05C
Aerosols	Sampling	Particulate	07D	14B
Electrostatic Precipitators		Fabric Filters	13I	
Scrubbers		Fugitive Dust	07A	
Filtration				

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 422
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE A18 – A01

EPA Form 2220-1 (9-73)

i

☆U.S. GOVERNMENT PRINTING OFFICE: 1979-640-013/4198 REGION NO. 4

PB 295227

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-79-044b
February 1979

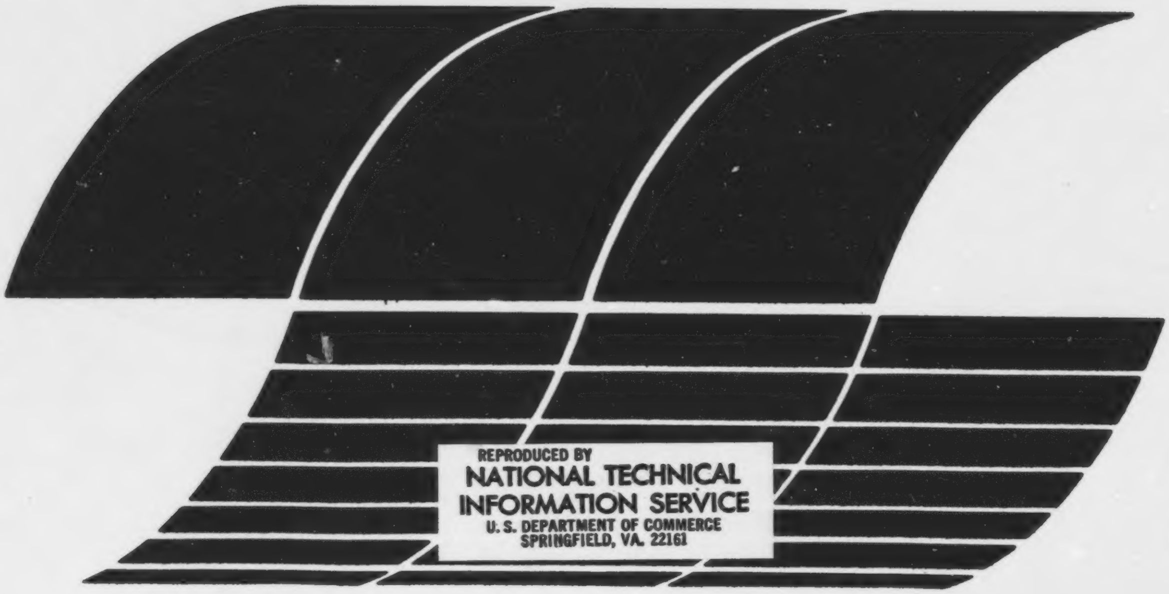
EPA

Symposium on the Transfer and Utilization of Particulate Control Technology:

Volume 2.

Fabric Filters and Current Trends in Control Equipment

Interagency Energy/Environment R&D. Program Report



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EPA-600/7-79-044b
February 1979

Symposium on the Transfer and Utilization of Particulate Control Technology:

Volume 2. Fabric Filters and Current Trends in Control Equipment

by

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Program Element No. EHE624

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

i.a

ABSTRACT

The papers in these four volumes of Proceedings were presented at the Symposium on the Transfer and Utilization of Particulate Control Technology, held in Denver, Colorado during 24 July through 28 July 1978 sponsored by the Particulate Technology Branch of the Industrial Environmental Research Laboratory of the Environmental Protection Agency and hosted by the Denver Research Institute of the University of Denver.

The purpose of the symposium was to bring together researchers, manufacturers, users, government agencies, educators and students to discuss new technology and to provide an effective means for the transfer of this technology out of the laboratories and into the hands of the users.

The three major categories of control technologies, electrostatic precipitators, scrubbers, and fabric filters were the major concern of the symposium. These technologies were discussed from the perspectives of economics; new technical advancements in science and engineering; and applications. Several papers dealt with combinations of devices and technologies, leading to a concept of using a systems approach to particulate control rather than device control.

These proceedings are divided into four volumes, each volume containing a set of related session topics to provide easy access to a unified technology area.

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FABRIC FILTER USAGE IN JAPAN

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ABSTRACT

The present situation of Japanese fabric filter manufacturing companies, including the four popular types of dust dislodging methods and their fields of application, is briefly described. Recently, the envelope type of felt fabric has also become popular.

The designs and operation of two novel types of fabric filters recently developed in Japan are explained. One of them is a self-regenerating filter with parallel fibers planted on a coarse mesh fabric, and the other a pulsating reverse air type of the envelope felt filter. In the first type, the filtering velocity is usually 1 to 3 m/sec, and the collection efficiency, when a corona charger is added, is nearly equal to that of a conventional fabric filter. The filters of the first type are compact in space and low in operating cost. Therefore, their applications in air ventilation field are gradually increasing.

INTRODUCTION

Most fabric filters used in Japan are similar to those in the United States, because several Japanese filter manufacturing companies are the licensees of American companies as shown in Table 1. The Japanese filter manufacturing companies are mainly middle or small sized. They compete severely with each other in the sales market, especially after the oil embargo, which has led to the current recession of Japanese industry. However, most industries show a preference for fabric filters rather than scrubbers and electrostatic precipitators, because filters are reliable for higher collection efficiencies and require only moderate operating costs. There are four popular dust dislodging methods used in Japan; reverse air or pressure (collapse), shaking, pulse jet, and pulsating reverse air. The envelope type of felt fabric has recently become as popular as the conventional cylindrical bag type, because the former is compact in space and easy to handle in maintenance.

Figure 1 is an example of the reverse air type of a cylindrical bag filter designed in Japan with a top inlet and a filter aid pipe. Figure 2 shows another example of the reverse air type of an envelope bag filter with an inlet plenum chamber, which has the advantages of high resistance to abrasive particles, uniform gas distribution, and easy maintenance. There is no usage of fabric filters in Japan for cleaning the exhaust gas of a power station or a cement kiln, in contrast to those in the United States. A few large fabric filters are applied to the ventilating exhaust of steel or metal manufacturing plants, and to the exhaust of cement clinker coolers and electric arc furnaces. They are mostly the reverse air type.

Recently, two novel types of fabric filters have been developed in Japan. One is a pulsating reverse air type of the envelope felt filter, and the other is a self-regenerating filter with parallel fibers planted on a mesh fabric. These two types are explained in the following sections.

SELF-REGENERATING FABRIC FILTER "LONMESH CYCLEANA"

Figure 3 shows the cross-section of a special filter "Lonmesh" with synthetic parallel fibers electrically planted on a coarse mesh base. The packing density of the fibers increases in the flow direction, which has the advantages of low pressure loss and high collection efficiency. The dust layer collected on the fabric can easily be cleaned by a travelling vacuum cleaner, which is similar to a household electric sweeper, because the planted fibers of 2 to 7 mm length are fixed in the same direction. Therefore, the filter fabric is automatically cleaned and regenerated in situ, and can be used for a few years. Some examples of the performances of these filters are given in Figures 4 and 5, and their constructions are shown in Figure 6. The filtering velocity (air to cloth ratio) of these filters is mainly 1 to 3 m/sec, which is similar to that of a conventional ventilating air filter. Their collection efficiency is similar to that of a cyclone and higher than that of a conventional air filter. However, these filters do not work well for dust concentrations higher than $0.1 g/m^3$.

Shown in Figure 7 is a newly developed electrostatic type, which is a combination of an electrostatic corona charger and the Lonmesh filter. The collection efficiency of this filter at low filtering velocities is nearly equal to that of a conventional fabric filter as given in Figures 8 and 9. Electrostatic charges on particles emhance the agglomeration of air borne particles, thereby, increasing the collection performance and reducing the pressure loss because of increased void of the collected dust layer. These types are compact in space and resonable in price because of the higher filtering velocity, which is nearly 100 times of that of a conventional bag filter. The operating cost is also low, because of the lower pressure loss as shown in Figures 8 and 9. The dust layer deposited on the electrodes is periodically dislodged by mechanical hammering, while the regeneration of the fabric is automated by a vacuum cleaner as in the non-electric types.

Several examples of the applications are given in Table 2. The usage includes air conditioning filters for underground shopping centers, subway stations, business buildings and larger stores, and dust collectors for pneumatic conveyors and intake air or exhaust gas of industrial processes. This filter meterial "Lonmesh" has been patented in the United States of America, the Great Britain, West Germany, France, and Japan.

PULSATING REVERSE AIR BAG FILTER "VIBRO-CLEAN"

This filter, which has no flow damper for cleaning, is equipped with a special cleaning system of vibrating reverse air, of which the frequency is 1000 to 1500 Herz, and the vibrational amplitude of fabric is less than 1 mm. As shown in Figure 10, the bag housing is cylindrical, and the filter elements are arranged radially in single to triple rows according to the required filtration area. The holding plate of filter retainers provides rectangular holes, from which envelope bags are hanged. The pulsating compressive reverse air is actuated by a blower and a high speed rotary valve mounted on the top deck, and blows into each envelope bag through a rotating blow pipe, a switching valve and a hole in the holding plate. The cleaning operation is applied to one element at a time, and continues successively one after another until an automatic switch is activated. Therefore, the effective filtering area changed very little through the whole operation period.

The dust laden gas enters tangentially into the bag chamber and the particles are collected on the outside surface of the fabric bag. More than 1000 units have been manufactured in nearly 10 years. Due to the effective cleaning action, they can efficiently collect wet or adhesive dust, which is difficult to remove form the fabric by conventional cleaning methods. Therefore, this type of filters are used in the treatment of highly humid air in foundry sand process, gas from coke handling and discharge processes in a coke oven, and exhaust from a sludge incinerator or a wood chip boiler. Table 3 shows a few typical examples of the applications.

TABLE 1. JAPANESE LICENSEES OF FOREIGN DUST COLLECTOR MANUFACTURING COMPANY

Japanese Licensee	Foreign Company
Ashizawa Iron Works Tokyo	Siemens A.G. Erlangen, West Germany
Hokoku Kikai Co. Fukuyama	Fluidizer Inc. Hopkins,Minn., U.S.A.
Hosokawa Iron Works Osaka	United Filter Corp., Mikro Pul Div., N.J., U.S.A.
"	Donaldson Corp. Inc., Torit Div., St. Paul. Minn., U.S.A.
Japan Air Filter Co. Hiratsuka	American Air Filter Co. Inc. Louisville, Ky., U.S.A.
Mitsui Miike Seisakusho Tochigi	Air Industry Co. Paris, France
Nihon Donaldson Co. Tokyo	Donaldson Corp. Inc. Minneapolis, Minn. U.S.A.
Nitta Zeratin Co. Tokyo	American Precision Ind. Inc. Buffalo, N.Y., U.S.A.
Sanko Seisakusho Yokohama	Gesellschaft für Entstaubungs-technik AG Sursee, Switzerland
Sinto Dust Collector Co. Nagoya	Wheelabrator Frye Inc. Pittsburgh, Pa., U.S.A.
Sumitomo Heavy Machinery Tokyo	Joy Manuf. Co. Ltd., Western-Precipitation Div., LosAngels, Cal. U.S.A.
Taiyo Chuki Co. Osaka	Carborundum Co. Knoxville, Tenn. U.S.A.

Table 2. EXAMPLES OF INDUSTRIAL APPLICATION OF "LONMESH" FILTER

Application plant		Induction Furnace Canopy Hood	Casting Foundry Exhaust	Exhaust of Chemicals for Fiber Treatment
Filter Type		Endless Fabric	Electrostatic + Endless Fabric	Electrostatic + Endless Fabric
Filtering Velo.	m/sec	1.9	1.9	1.5
Inlet dust concentration	mg/m_N^3	6 - 26	20 - 30	22 - 36
Outlet dust concentration	mg/m_N^3	1.4 - 6	1 - 4	0.4 - 0.7
Collection Efficiency	%	65 - 77	85 - 95	98
Temperature	°C	4 - 65	4 - 65	5 - 40
Gas flow rate	m_N^3/min	2000	5300	400
Pressure loss	mmH_2O	30 - 60	30 - 60	20 - 40
Regenerating Suction Press.	mmH_2O	-1500	-2500	-1500
Regenerating Dust Collector	m^3/min	Bag Filter 6	Cyclone and Bag Filter 32	Bag Filter 6
Dust Size Distribution (wt. base)		<1μm 26% 1- 4 19 4-10 27 10-15 17 15-20 5 20< 6	<0.4μm 10% 0.4-1.0 11 1- 6 27 6-10 15 10-20 22 20< 15	<0.55μm 17% 0.55-1.3 28 1.3-2.0 21 2.0-3.9 20 3.9< 14

Table 3. VARIOUS APPLICATIONS OF "VIBRO-CLEAN" FILTER

Application	Fabric	Filtering Velocity $(\frac{m}{min})$	Temp. (°C)	Moisture in Gas (vol %)	Inlet Dust Concentration $(\frac{g}{m^3_N})$	Outlet Dust Concentration $(\frac{mg}{m^3_N})$	Press. Lo (mmH$_2$O)
Asphalt Plant	Conex Felt 450 g/m^2	1.5 - 1.7	120-200	10 - 15	15 - 100	2 - 15	120 - 170
Wood Chip Boiler	Conex Felt 450 g/m^2	1.4 - 1.8	130-170	10 - 15	2 - 5	1 - 10	150 - 250
Melting Furnace for Scrap Batteries	Pylen Felt 500 g/m^2	1.2 - 1.3	80-95	10 - 20 SO_x 8000ppm	10 - 60	1 - 5	120 - 200
Sludge Incinerator	Woven Conex 450 g/m^2	0.8	120-150	5 - 15	5 - 10	1 - 10	100
Impeller Breaker and Conveyors for Coking Coal	Woven Wooly Tetoron	1.5	0-30	1.5- 7	3 - 5	< 1	70 - 100
Coke Oven Discharge Doors	"	1.3	0-80	-	< 7	2.5	60 - 80
Gypsum Calciner	Conex Felt 500 g/m^2	1.4	120	-	10	5	170 - 200
Calcined Gypsum Grinder	Tetoron Felt 750 g/m^2	1.5	50-70	< 1	60	20	150
Sintering Plant in Steel Mill	Tetron Felt 500 g/m^2	1.7	< 140	-	15 - 20	1 - 10	150 - 200
Vent from Closed Circuit Grinding System for Phosphate Rock	Pylen Felt 500 g/m^2	1.2 - 1.6	40-60	5 - 17	3 - 10	1 - 10	150 - 200
Pigment Mixer	Pylen Felt 500 g/m^2	0.8	0 -30	Atmospheric	0.02 - 5	< 0.08	130

Note: Conex : Aromatic Polyamid Fibre made in Japan, Tetron: Polyester Fibre made in Japan, Pylen: Polypropylene Fibre made in Japan

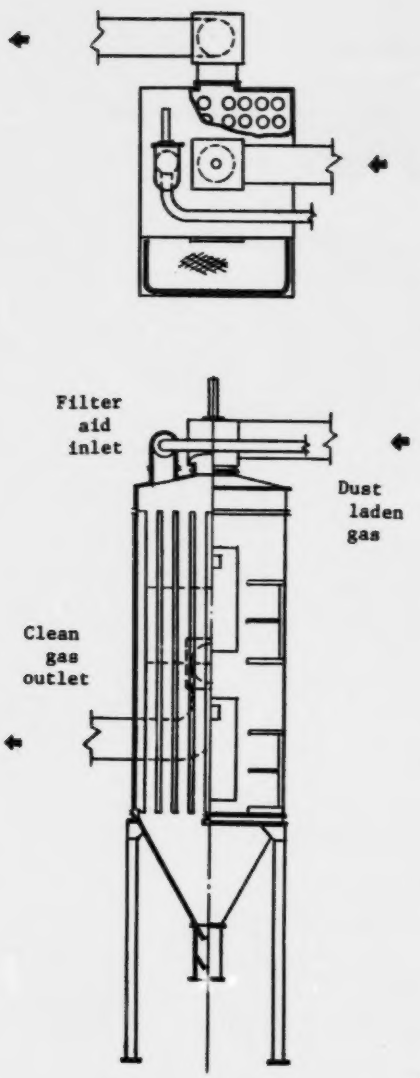

Filter aid inlet
Dust laden gas
Clean gas outlet

Figure 1. Example of top inlet cylindrical fabric filters with reverse air cleaning and filter aid pipe. (Kurimoto)

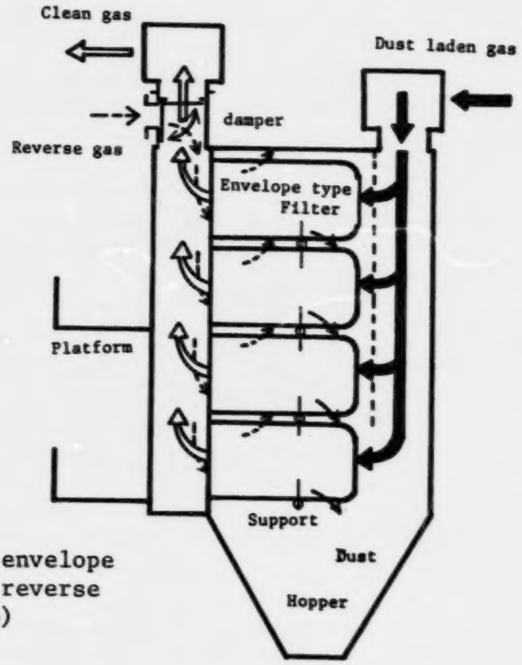

Clean gas
Dust laden gas
damper
Reverse gas
Envelope type Filter
Platform
Support
Dust
Hopper

Figure 2. Example of envelope fabric filters with reverse air cleaning. (Sinto)

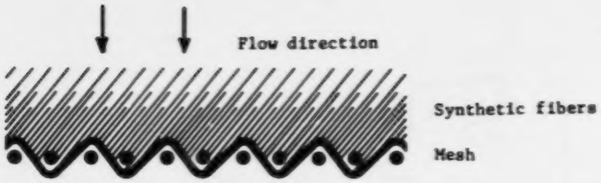

Flow direction
Synthetic fibers
Mesh

Figure 3. Schematic sketch of cross section of "Lonmesh" fabric

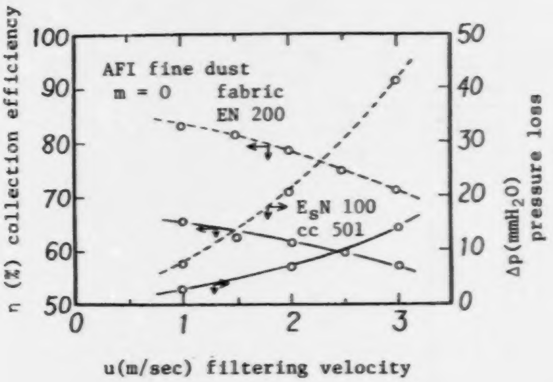


Figure 4. Experimental initial performances of two "Lonmesh" fabrics for filtering velocity

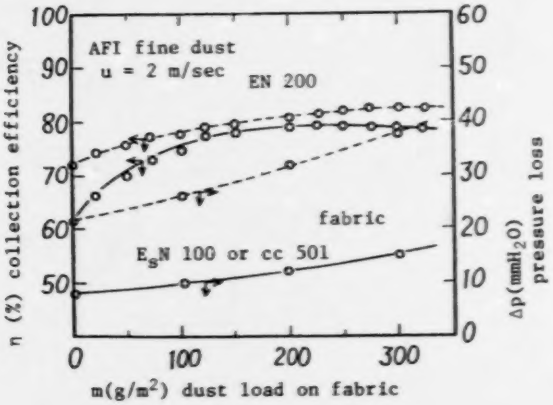
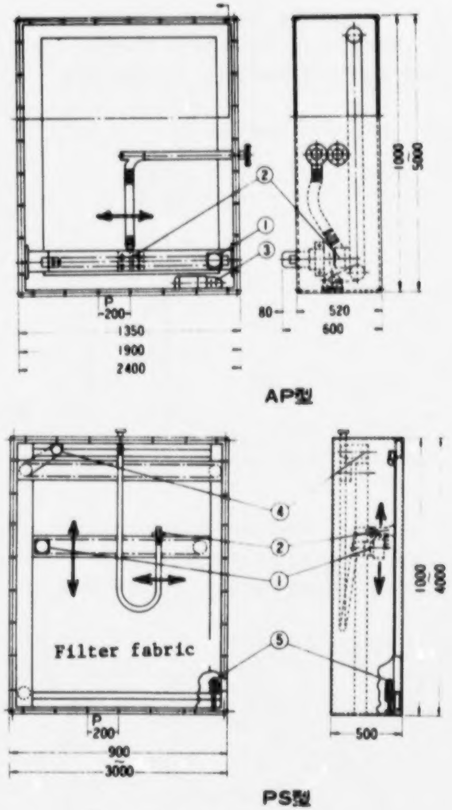


Figure 5. Experimental performances of two "Lonmesh" fabrics for dust load on fabric



②
①
③
P
-200-
1350
1900
2400
80
520
600
1000
5000
AP型
④
②
①
⑤
Filter fabric
P
200
900
3000
500
1000
4000
PS型

1) Driving motor for regenerating suction port
2) Suction port
3) Driving motor for filter fabric
4) Driving motor for regenerating frame
5) Tension spring for filter fabric

Figure 6. General drawings of two types of "Lonmesh" filter

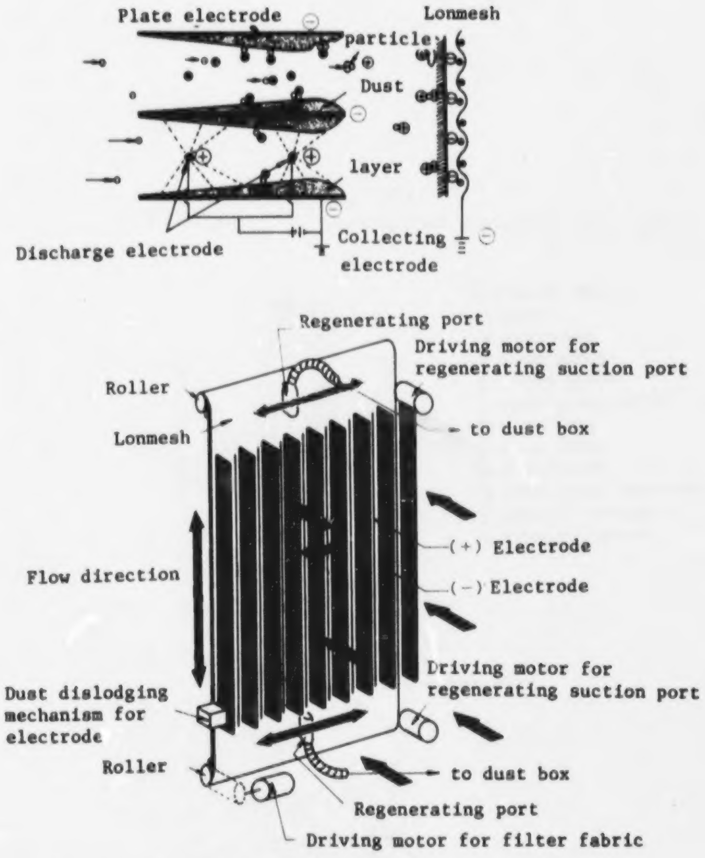


Plate electrode
Lonmesh
particle
Dust
layer
Discharge electrode
Collecting electrode
Regenerating port
Driving motor for regenerating suction port
Roller
Lonmesh
to dust box
(+) Electrode
(−) Electrode
Flow direction
Driving motor for regenerating suction port
Dust dislodging mechanism for electrode
Roller
to dust box
Regenerating port
Driving motor for filter fabric

Figure 7. Electrostatic "Lonmesh" filter

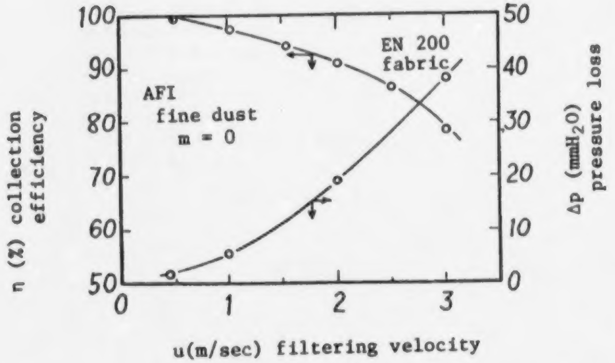


Figure 8. Experimental initial performances of electrostatic "Lonmesh" filter for filtering velocity

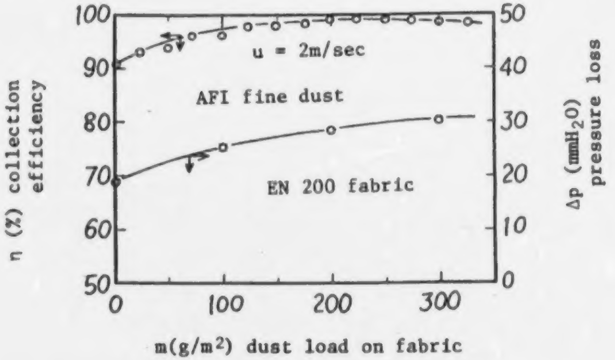


Figure 9. Experimental performances of electrostatic "Lonmesh" filter for dust load on fabric

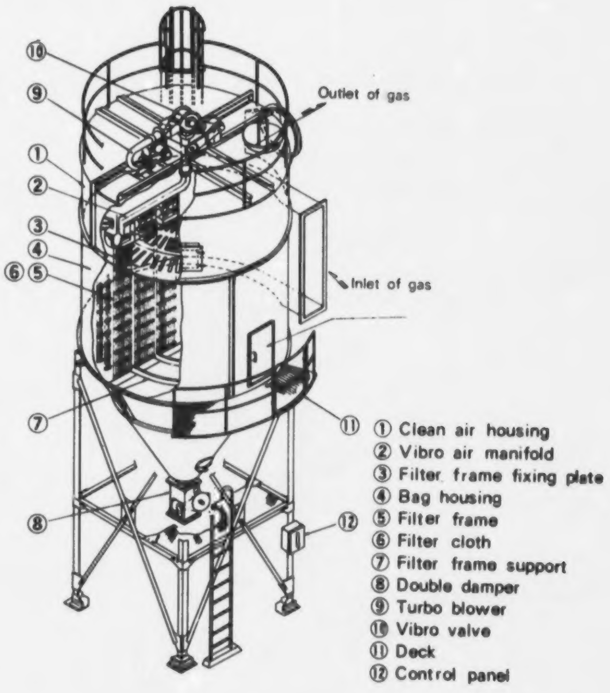

⑩
⑨
①
②
③
④
⑥ ⑤
⑦
⑧
⑪
⑫
Outlet of gas
Inlet of gas
① Clean air housing
② Vibro air manifold
③ Filter frame fixing plate
④ Bag housing
⑤ Filter frame
⑥ Filter cloth
⑦ Filter frame support
⑧ Double damper
⑨ Turbo blower
⑩ Vibro valve
⑪ Deck
⑫ Control panel

Figure 10. Pulsating reverse air type "Vibro Clean" filter

PERFORMANCE OF A PULSE-JET FILTER AT HIGH FILTRATION VELOCITIES

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INTRODUCTION

Increased superficial filtration velocity (air to cloth ratio) through a fabric filter allows use of a more compact device that is less expensive to purchase. Pulse-jet cleaned filters operate at velocities greater than those used for filters cleaned by shaking or reverse air, and form a natural starting point for development as high velocity devices. Conventional pulse-jet filters operate at filtration velocities of 30 to 50 mm/s (6 to 10 cfm/ft^2) although somewhat higher velocities are sometimes economical for filters not operated around the clock.[1]

The Environmental Protection Agency has supported research at the Harvard Air Cleaning Laboratory to characterize and improve the performance of pulse-jet cleaned filters operated at high filtration velocities. The findings of this research have been published in detail as the work progressed.[1-11] This paper summarizes this information, and discusses general principles that arise from examination of the data as a whole.

BAG-FABRIC INTERACTION

Laboratory tests have shown that 80 to 90% of the dust deposit on woven fabrics cleaned by shaking or reverse air is removed during cleaning.[12] In contrast, for felt bags cleaned by pulse-jet, bag cleaning is considerably less effective, as less than one per cent of

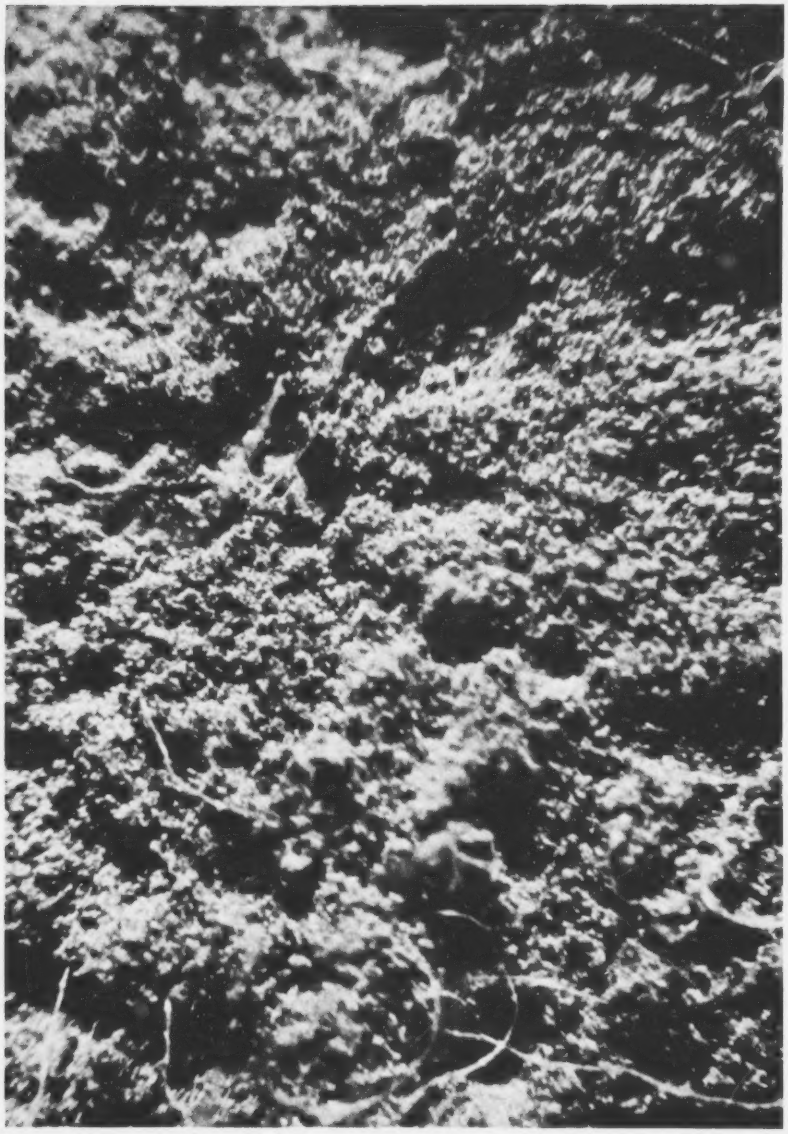

Figure 1. Dust deposit on the surface of a pulse-jet cleaned felt bag

the total dust mass on a bag arrives at the hopper after pulse cleaning.[4,11] The tendency of the bag to retain collected dust, called "mass retention,"[10] arises because the cleaning pulse does not separate dust from the fabric, because dust freed by a cleaning pulse redeposits on the bag rather than falls to the hopper, or from both causes.

Figure 1 is a photograph of the dust deposit on a pulse-jet cleaned bag and shows felt fibers protruding from the dust/fabric matrix at the fabric surface. The dust deposit between the fibers appears to be much more discontinuous than the smooth filter cake seen on the surface of a woven fabric. At equilibrium, the amount of dust captured by the fabric during the interval between cleaning pulses is equal to the amount of dust transferred to the hopper by a cleaning pulse. The equilibrium areal density of the dust deposit on a felt at a velocity of 100 mm/s was measured to be about 400 g/m^2 by weighing the bags.[11] For these tests, the amount of dust fed to the filter between cleaning pulses corresponded to an areal dust density of about 3 g/m^2, only a small fraction of the total dust deposit on the bag. The total areal density of the dust deposit, therefore, was relatively constant throughout the cleaning cycle. The implications of this observation are that: 1) pulse-jet cleaning is ineffective, especially by comparison with the cleaning efficiency found for woven fabrics cleaned by shaking or reverse air and bag collapse, and 2) a substantial dust deposit exists on pulse-jet cleaned bags at all times, even immediately after cleaning. Dust retention on the fabric has a strong adverse effect on the penetration and pressure drop characteristics of pulse-jet cleaned filters.[9-11]

PENETRATION

The dust penetration characteristics of a pulse-jet filter were studied[3,5,6] to determine how dust passes through the bag. Penetration was found[3,6] to increase substantially with increasing filtration velocity, to increase somewhat with increasing particle size for particles between 0.3 and 5 micrometers in diameter, and to decrease sharply with time following a cleaning pulse.

Figure 2 is a plot of outlet mass flux (kilograms of dust penetrating per square meter of bag surface per hour) against filtration velocity with penetration mechanism as a parameter.[5] The two penetration mechanisms considered are straight through penetration, in which dust passes directly through the fabric and dust deposit without stopping, and seepage penetration, in which dust is first collected but then works through the filter at some later time. Outlet mass flux is the product of outlet concentration and filtration velocity. The data show that at a "conventional" filtration velocity of 50 mm/s, relatively little dust penetrated the filter. As filtration velocity increased, little or no dust penetrated straight through, although the amount of

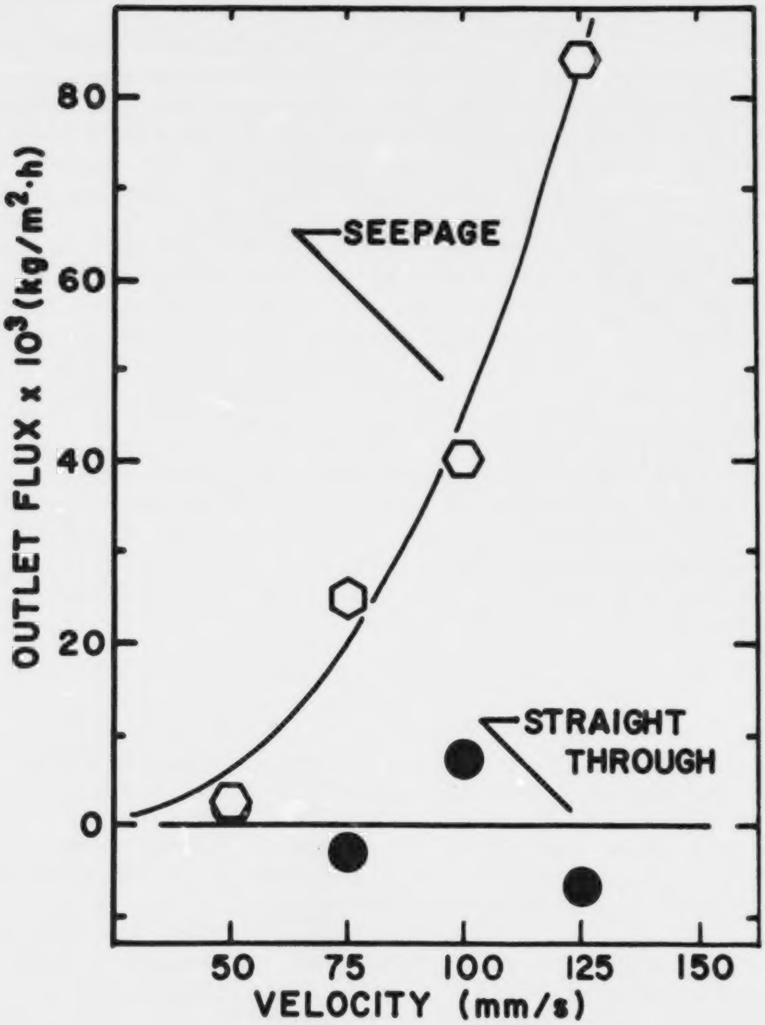

Figure 2. Outlet dust mass flux versus filtration velocity, penetration mechanism as parameter

dust that penetrated by seepage increased markedly. The increase in penetration found at high filtration velocities is due entirely to seepage.

A series of tests was performed with a three bag pulse-jet filter at five different filtration velocities from 50 to 125 mm/s. Two different inlet dust mass fluxes were used at each velocity, one double the other. Characteristics of the bags, dust, and cleaning procedures are given in Table 1. Figure 3 is a plot of outlet mass flux against filtration velocity found for these experiments, with inlet dust mass flux as parameter. It shows that outlet mass flux from the bags increased with filtration velocity, but did not depend upon the inlet dust mass flux. That is, whatever the inlet dust load, the outlet dust load remained constant within the accuracy and range of our data.

All this leads to the conclusion that dust penetration through a pulse-jet filter is not explained by conventional single fiber efficiency and media filtration theory, which predict that penetration of the larger particles, which contribute most to mass, should decrease with increasing filtration velocity, decrease with increasing particle size, and remain constant for changes in inlet dust loading. All these predictions are contrary to the trends observed in our experiments.[3,5,8,9] Therefore, it is clear that models used to predict pulse-jet filter behavior which are based on media filtration theory alone are inappropriate to explain pulse-jet filter performance.

Analysis of the dust mass retained by the fabric may help explain the observed penetration characteristics of the filter. A cleaning pulse blows the fabric open and away from the cage which supports it during normal filtration. At the end of the pulse the bag snaps back to its support cage and hits it sharply. At impact, some dust particles and agglomerates experience a deceleration force greater than the adhesive force which binds them in place, and in this way are driven from the fabric and into the cleaned gas stream. Seepage caused in this way accounts for the penetration characteristics found in experiments: (1) outlet mass flux and penetration should increase with increasing filtration velocity as has been found, because increased velocity would drive the bags back to their cages faster and cause the bags to hit their cages with greater impact, thereby dislodging more dust; (2) outlet mass flux and penetration should increase with increased particle diameter as has been found, because larger particles have a greater ratio of inertial force to adhesive force and are more likely to break from the dust/fabric matrix as the bag hits the cage; (3) outlet mass flux and penetration should decrease sharply after pulse cleaning, as has been found, if most dust passes through the fabric as a consequence of cleaning; and (4) outlet mass flux and penetration should be constant for differing inlet dust loadings, as has been found, because the rate at which dust passes through the bag should depend more upon the frequency and intensity of cleaning and perhaps upon the amount of dust retained by the bag than upon changes in inlet dust

Table 1. FILTER CHARACTERISTICS

Bags	
Type	Polyester needled felt
Weight	0.54 kg/m^2
Size	1.44 mm dia., 2440 mm long
Number	3
Treatment	None
Permeability	150 mm/s at 124 Pa
Supplier	Summit Filter Corp., Summit, NJ
Dust	
Type	Fly ash
Density	2200 kg/m^3
Count median dia.	0.3 micrometers
Standard geometric deviation	2.7
Cleaning Pulse	
Pressure	6.8 atm
Valve time	75 ms electrical, 240 ms actual
Interval	1 pulse/minute/bag

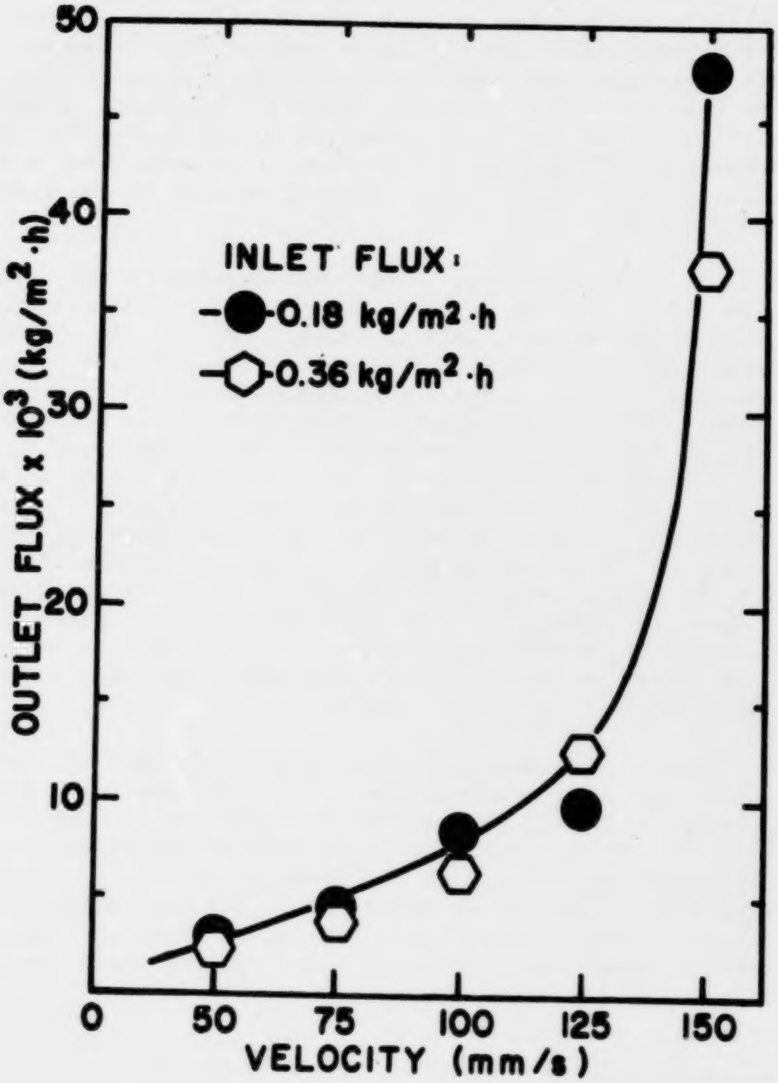

Figure 3. Outlet dust mass flux versus filtration velocity, inlet dust mass flux as parameter

loading.

PRESSURE DROP

In addition to filtration velocity, pressure drop across a pulse-jet filter depends both upon the total mass of dust retained by the fabric after cleaning and upon the areal distribution of that dust on the filter bags as well as upon the specific resistance of the dust deposit. Clearly, as dust mass retention increases and the dust deposit thickens, pressure drop should increase. Because pulse cleaning is ineffective, a considerable amount of dust remains on the fabric even after cleaning.[4,11]

The ratio of pressure drop after cleaning due to the residual dust mass on the filter bags to pressure drop caused by the additional dust deposited on a bag between cleaning pulses, $\Delta P_a/\Delta P_o$, is plotted in Figure 4 against the fraction, γ, of dust that remains on a pulsed bag after cleaning.[10] This figure shows that more effective cleaning has considerable potential for reducing pressure drop and extending the interval between cleanings in a pulse-jet filter. For example, at high filtration velocities more than 99% of the dust on a filter bag has been shown to remain on the bags after pulse-cleaning.[4,11] If cleaning effectiveness could be improved to the point where only 80% of the dust remained on the bag after pulse-cleaning, a conservative goal compared with the demonstrated effectiveness of other cleaning methods,[12] Figure 4 shows that pressure drop would decrease by a factor of about 25. Alternatively, the interval between pulse-cleanings could be extended by a factor of about 25, with subsequent increase in fabric life and decrease in cleaning energy consumption.

The shape of the retained dust mass profile along the bags has been found to influence pressure drop. For the same total dust mass on a bag, pressure drop is higher if the dust deposit is uniform over the bag surface than if the dust deposit profile is skewed so that areal density is higher in some places and lower in others.[10] Measurements of the dust mass profile along pulse-jet filter bags using a beta gauge[11] showed fairly constant mass deposition along the bags except for the region immediately below the pulse venturi where less dust was retained.

FILTER MODIFICATIONS

Several changes have been made to the design of pulse-jet cleaned filters to improve performance at high filtration velocity. Cleaning pulses have been modified to reduce the impact of the bags on their support cages at the end of a cleaning pulse.[7,8] Less impact reduces seepage of dust through the filter bags by reducing the forces available to dislodge retained dust from the fabric. Bag life may also be

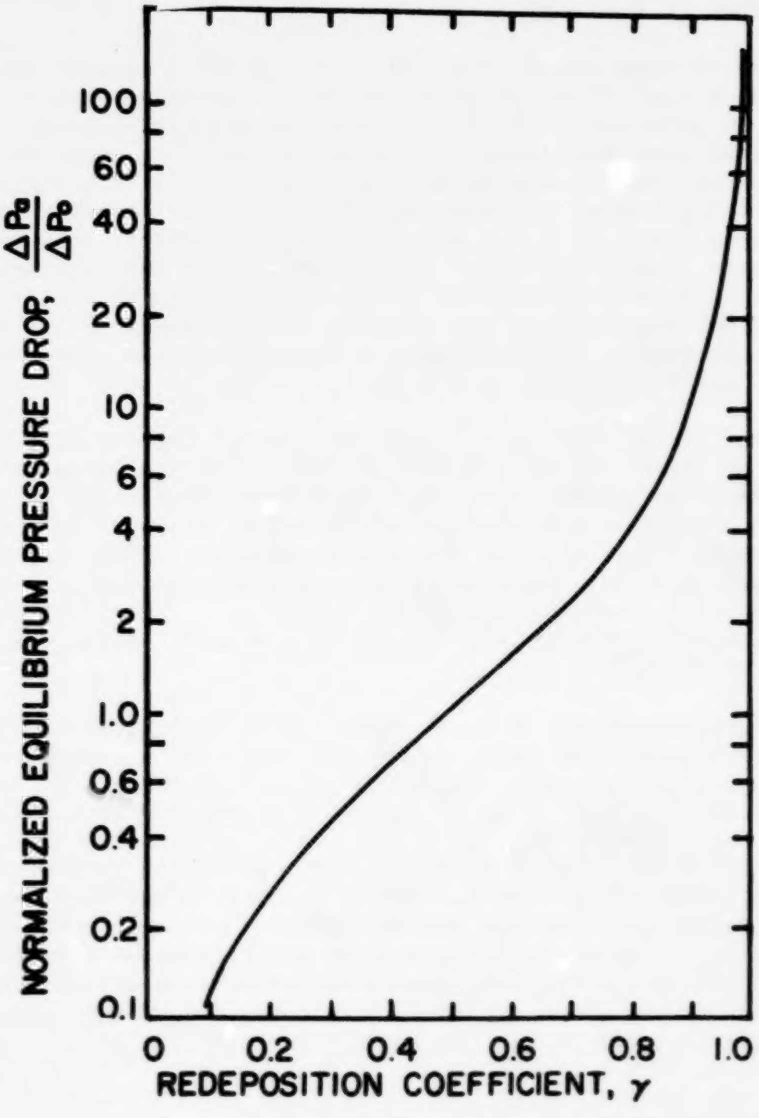

Figure 4. Ratio of pressure drop after cleaning to pressure drop due to dust deposited between cleaning pulses, $\Delta P_a/\Delta P_o$, versus fraction of dust that remains on bag after cleaning, γ

extended by reducing bag wear at the points where the fabric hits the cage. This was accomplished by reducing pulse pressure over a period of about 1.5 seconds instead of a few milliseconds for the standard cleaning pulse, permitting the bag to return to its cage much more gradually than it does with a normal pulse.

Results of experiments using modified and normal pulses are shown in Figure 5, a plot of outlet mass flux vs. filtration velocity with pulse type as parameter. For both normal and modified pulses, outlet flux increases with increasing filtration velocity.[7,8] However, for modified pulses the increase is much more gradual. At the highest filtration velocity tested in these experiments, 150 mm/s, outlet flux was reduced by about 50% using modified cleaning pulses, compared to normal pulses. Media filtration theory, which does not consider seepage as a means by which particles can penetrate a fabric filter, cannot explain why the shape of the cleaning pulse affects outlet mass flux. Seepage theory, which relates outlet flux to the forces which act on the dust deposit during cleaning, provides a better explanation.

The location of the aerosol inlet to the filter housing has also been found to affect filter performance significantly during high velocity operation.[9] Figure 6 is a plot of filtration velocity vs. outlet mass flux for filters with top and bottom inlet; Figure 7 is a similar plot for pressure drop against filtration velocity. Inlet location has little effect on filter performance at a conventional velocity of 50 mm/s. However, as velocity increases, outlet dust flux and pressure drop increase much more rapidly for the bottom inlet filter than for the top inlet filter.

This occurs because, with the bottom inlet design, the unfiltered aerosol sweeps vertically upward along the bags. This retards the settling of dust freed by a cleaning pulse so that is redeposits on the filter bags before it has time to fall to the hopper. Conversely, a filter with gas inlet at the top of the bag housing causes the aerosol to sweep vertically downward along the bags, and helps to convey freed dust to the hopper below. These effects are more pronounced at higher filtration velocities, because vertical aerosol velocity within the filter housing increases in proportion to the filtration velocity through the bags. This may cause mass retention to decrease for pulse-jet filters with top aerosol inlet. An alternative explanation is that the dust deposit is different for the bottom inlet filter, due to direct fallout of larger particles to the dust hopper. Fallout would reduce the mean size of particles collected on the filter bags for the bottom inlet design, increase the specific resistance of the dust deposit, and thereby increase pressure drop. These effects have also been noted for a shaker-cleaned filter, for which hopper fallout and particle size elutriation effects along the bags were described for filters with top and bottom aerosol inlet.[13,14]

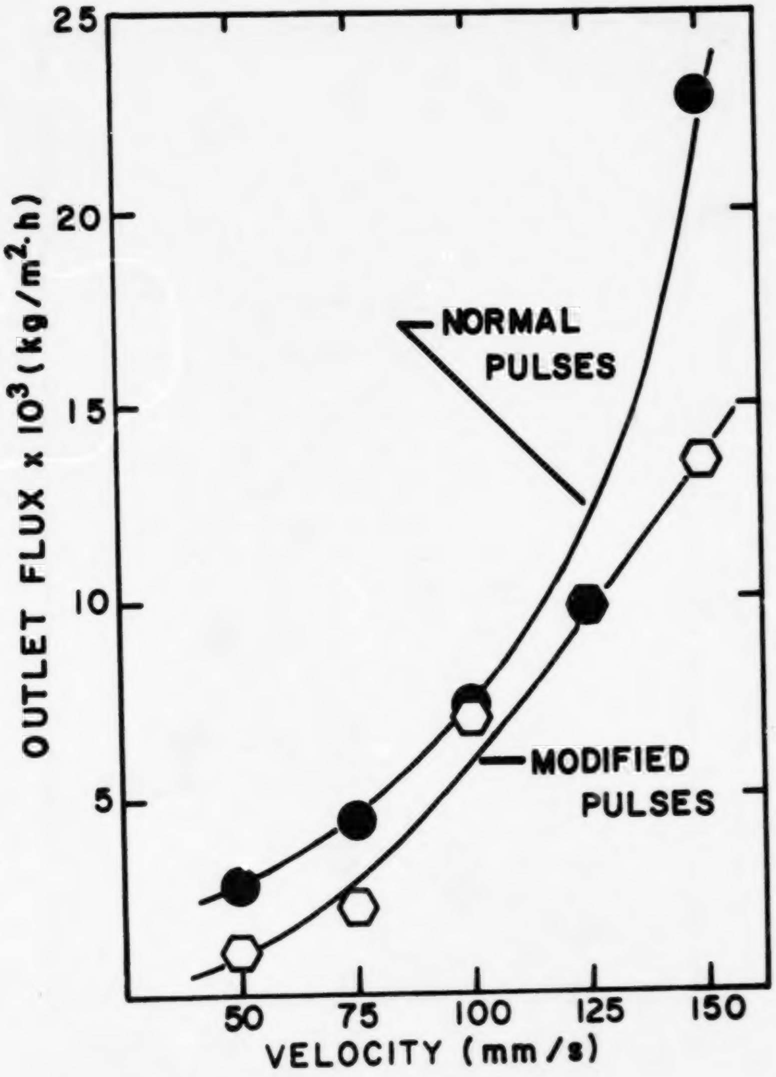

Figure 5. Outlet dust mass flux versus filtration velocity, pulse type as parameter

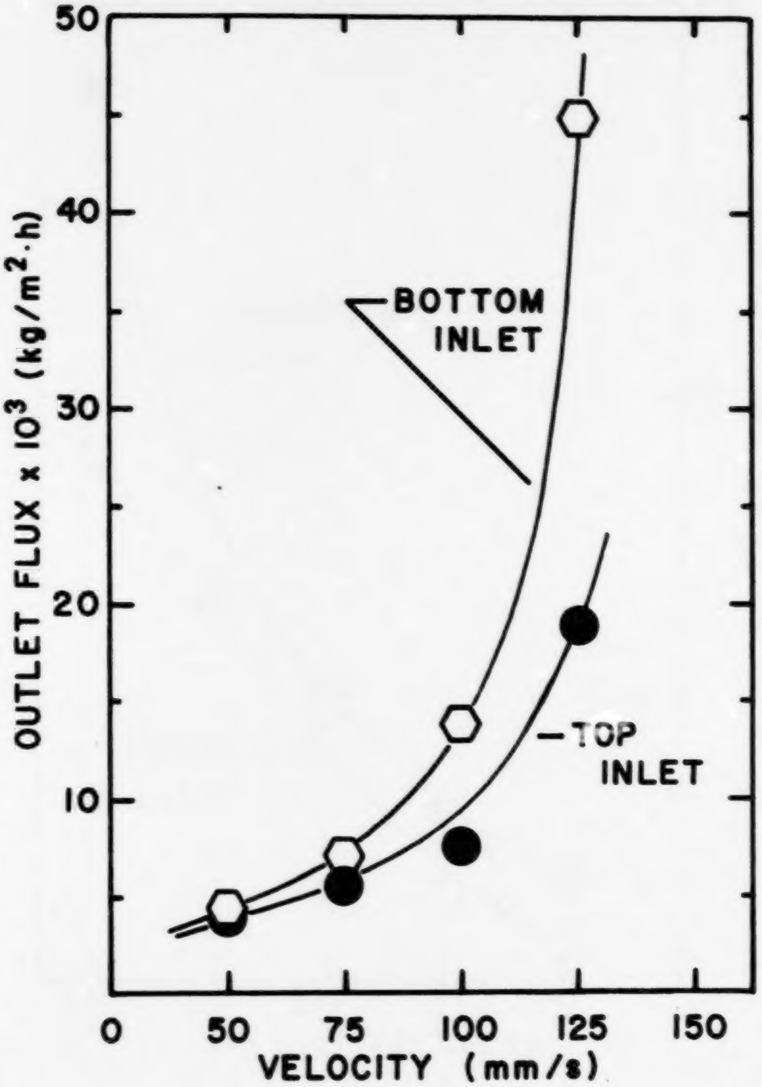

Figure 6. Outlet dust mass flux versus filtration velocity, inlet location as parameter

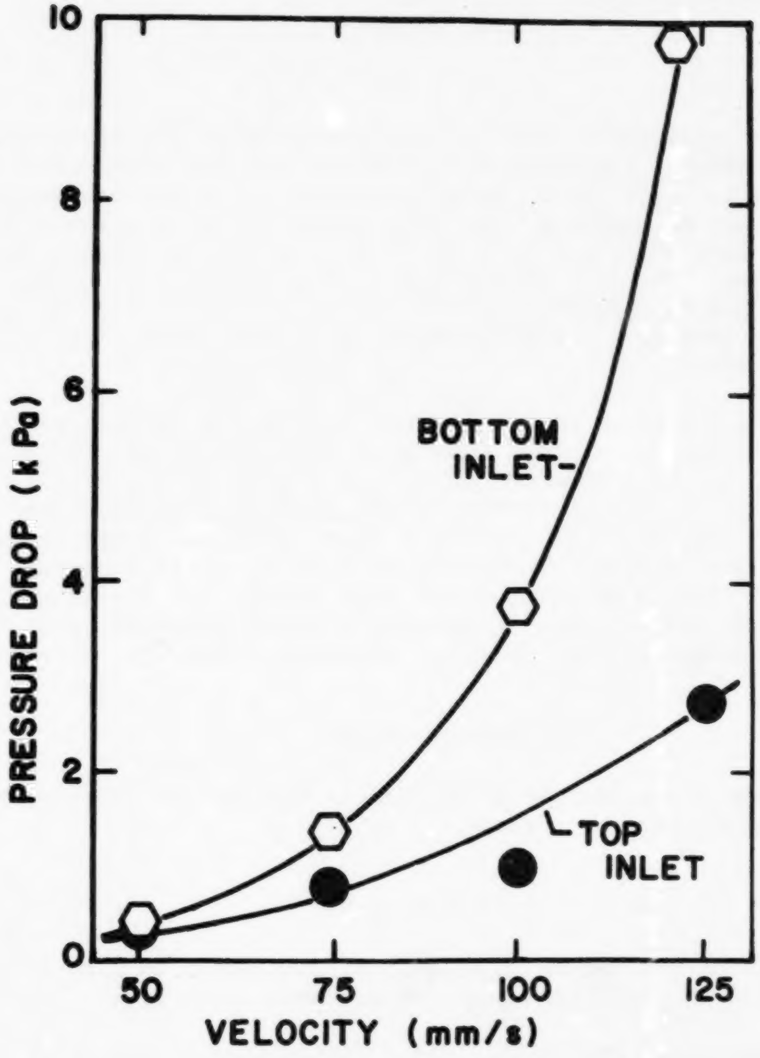

Figure 7. Pressure drop versus filtration velocity, inlet location as parameter

Decreased mass retention on the bags accounts for the observed decrease in pressure drop for filters with top aerosol inlet because filtered gas passes through a thinner dust deposit. Decreased mass retention also accounts for decreased dust penetration in that lower pressure drop drives the bag back against its cage less forcefully at the end of a cleaning pulse.

SUMMARY

The size and initial cost of pulse-jet cleaned filters decrease as filtration velocity increases, but pressure drop and penetration increase as well. This occurs because pulse-jet cleaning becomes progressively less effective to the point where only a fraction of one per cent of the dust deposited on a bag arrives at the dust hopper after a cleaning pulse. The rest of the dust remains on the bag because it is locked into the felt fabric structure and cannot be removed by pulse-cleaning, or because after pulse-cleaning it redeposits as it falls toward the hopper.

However, there are excellent opportunities for improving the performance of pulse-jet cleaned filters at high filtration velocities. For example, modified cleaning pulses and changes in filter housing design such as relocation of the aerosol inlet have an important influence on dust mass retention, which in turn, greatly affects the performance of the filter. If cleaning efficiency can be improved, reductions in filter pressure drop and dust penetration will result. A program to implement these findings and develop additional ones is continuing at the Harvard Air Cleaning Laboratory under EPA sponsorship.

ACKNOWLEDGEMENT

This work was supported by EPA grants R801399 and R804700, Dr. James H. Turner, project officer.

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ELECTROSTATIC EFFECTS IN FABRIC FILTRATION

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ABSTRACT

Using a bench scale experimental filtration test unit and supporting instrumentation, information has been obtained to reemphasize the critical role of electrostatics in the collection process. Electrostatics serve to explain differences in pressure drop, collectability, cleanability and efficiency. By comparing filtration data obtained with fabrics of different electrical properties in the collection of a variety of industrial particulates, performance is related to the electrostatic charge polarity, magnitude and sometimes discharge rate of the media.

INTRODUCTION

The following is a detailed summary of a report submitted to the Environmental Protection Agency under a Grant shared with Professor Gaylord W. Penney. Professor Penney's report, directed primarily to the fundamentals of the problem, will issue as Volume I and mine more practically oriented, will issue as Volume II in a separate publication.

Whitby and Liu* have demonstrated that electrical forces are much stronger than gravitational, thermal and adhesion forces for particles in the 0.1 to 1 μm range. This is the critical particle size range, healthwise, and it's this electrical influence on the filtration process that I want to stress.

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*Whitby, K. T., and B. Y. H. Liu, The Electrical Behavior of Aerosols. In: Aerosol Science, Davies, CN. (Ed.); New York, NY, Academic Press, 1966.

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Before considering the details of electrostatic involvement in the filtration process, the following generalizations (Table 1) are offered. May I suggest that each of you compare these observations with your own experience.

TABLE 1
ACCORDING TO BENCH SCALE FABRIC FILTRATION TEST RESULTS AND SUPPORTING DATA, FILTRATION PERFORMANCE:

1...*differs with changes in only the fiber make-up of similarly constructed fabrics,*

2...*differs with changes in only the construction of fabrics made from the same kinds of fibers,*

3...*differs with changes in the surface properties of the same fabrics,*

4...*differs with changes in the surface properties of the same particulate,*

5...*appears to be influenced critically by the electrical properties of both the particulate and the filter fabric.*

6...*is enhanced significantly by electrostatic features of the fabric filter that promote the formation of an aggregated, porous type cake.*

7...*is optimized by suitable balancing of the electrostatic features of the particulate and the collecting fabric.*

FUNDAMENTALS OF ELECTROSTATICS

Although the basic concepts of electrostatics are treated in Part I by Professor Penney, it is important here to establish the ground rules. First of all, it is necessary to accept the concept that all materials are subject to charging often by simple contact but more effectively by frictional contact or by rubbing. Whenever the materials are different and especially when they are reasonably good insulators, they develop and retain charges of opposite polarity (one becomes electropositive and the other becomes negative). The intensity or magnitude of the charges tend to increase as the substances are more widely separated in the triboelectric series and as they increase in roughness. The third electrostatic characteristic is that related to the durability of the charge. A low rate of charge loss indicates insulating type properties while high rates of charge dissipation are common in materials of high conductivity.

FABRIC CHARGING AND TRIBOELECTRIC PROPERTIES

The electrostatic charging-evaluation technique that has been described and that will appear in the EPA report, will not be discussed here. Suffice it to say that by means of this controlled fabric-fabric rubbing practice, it has been possible to develop a triboelectric series such as shown for a number of commercial filter media in Table 2. Most significant in this listing is the consistent electropositive location of such fibers as wool and nylon; the electronegative features of Teflon, and Kevlar, mostly the mid position of the acrylics and the wide range of locations for the polyesters.

PARTICULATE CHARGING

Particulates also become charged and White= as well as others have stated that it's almost impossible to avoid charging under normal handling conditions. Of course, drying and especially grinding processes produce increasingly high particle charges. Theoretically, at least, it should be possible also to locate particles in the same triboelectric series with fabrics. Despite numerous problems that will be considered in Volume I of this report to EPA, Professor Penney, was successful by using an impingement procedure to suggest that silica could be located in the TE Series. These results, shown in Table 3, indicate silica to be in about a -3 position. The need for more of this kind of information will become evident as the influence of fabric-particulate charge relationships are discussed.

ELECTRICAL RESISTIVITY AND CHARGEABILITY

Fabric Resistivity

This important quality of filter fabrics serves to indicate the cleanliness of the material as well as its inherent charge retention features. A simplified test practice referred to as the Square Method is also described in the EPA report. Some resitivity data showing a relationship with apparent antistatic properties are shown in Table 4.

=White, H. J. Industrial Electrostatic Precipitation, Reading, MA, Addison -Wesley (1963).

TABLE 2. ESTIMATED* TRIBOELECTRIC POSITION OF SOME FILTER FABRICS

+8 ·
● 21 & 97 WOOL/NYLON, 21 [20%]
● 104 WOOL, HOM 8 [80%]
● 78 WOOL/NYLON [80%]
APPROXIMATE LOCATIONS

+6 -- NYLON 800 B (REFERENCE) ● 112 DACRON [80%]
● 102 WOOL, HOM 7 [85%] ● 23 WOOL/COTTON [100%]
+5 · ● 122A DRALON T (DYED) NAP
● 15 DACRON [50%] ● 98 NYLON [45%] ● 122B DRALON T (DYED)
+4 ·
● 103 WOOL, HOM 6 [80%]
● 18 POLYESTER [90%]
+3 · ● 110 NYLON, NAP [75%]
● 117 ACRYLIC, ZC [90%] ● 114 POLYESTER/GLASS [90%]
+2 ·
● 116 POLYESTER [75%]
● 6 KODEL [20%] ● 18 POLYESTER, NAP [25%]
● 93 DACRON [40%]
● 120 DRALON T [30%] ● 19 POLYESTER & PVA [45%]
+1 ·
● 9 50/50 DA/OR [35%]
● 77 GLASS [77%] ● 2 NOMEX [60%]
● 118 POLYESTER [70%]
0 ·
● 7 ACRYLIC, Z [40%]
● 107 DACRON, NAP [60%] ● 87 DRALON T [85%] ● 41 ACRYLIC, Z [25%]
● 12 ORLON [30%] ● 42 ORLON [60%]
−1 ·
● 10 75/25 DA/OR [40%]
● 3 DRALON T [30%]
−2 ·
● 16 DACRON SI [30%] ● 83 POLYPROPYLENE [50%]
−3 ·

−4 -- DARLAN S546 (REFERENCE)
● 90 GORE (NOMEX BASE) [75]
● 37 TEFLON [0%]
● 65 KEVLAR [45%]
APPROXIMATE LOCATIONS
−6 ·

*FROM TRIBOELECTRICIFICATION DATA BY PROPORTIONAL CALCULATIONS
[ ] = RELATIVE DISCHARGE RATE [LOSS (%) IN 2 MINUTES] AT 50% RH

NOTE: NUMBER PRECEDING EACH FABRIC IS AN ARBITRARY FABRIC REFERENCE NUMBER

TABLE 3
TRIBOELECTRIC POSITION OF SILICA, PG-C
(Relative To Some Fabrics)*

Fabric	Rel. TE Pos.	Dust charge, current x10^{-9}a Rel. to Fabric
97 - nylon/wool	∼+8	-4.5
15 - Dacron	+4.8	-1.4
9 - Dacron/orlon	+0.7	----
16 - Dacron	-2.5	-1.1
⇦	∼-3 Silica PG-C	⇨
89 - Gore (Tef/p.e.)	-3.6	+0.9
55 - Darvan (felt)	-3.7	----
37 - Teflon	∼-6	+3.8
65 - Kevlar	∼-8	+4.2

* Penney, G. W. - Progress Report of October 15-November 15, 1976 to EPA Grant No. R-803020.

TABLE 4
FABRIC RESISTIVITY[a] @ VS. ANTI-STATIC RATING

Volume/Vertical resistivity[b] (ohm-cm)	Surface/Horizontal resistivity[c] (ohm)	Anti-static rating
$>10^{11}$	$>10^{13}$	Nil
$10^{10}-10^{11}$	$10^{12}-10^{13}$	Poor
$10^{9}-10^{10}$	$10^{11}-10^{12}$	Moderate
$10^{8}-10^{9}$	$10^{10}-10^{11}$	Fairly good
$<10^{8}$	$<10^{10}$	Good

[a] ASTM D257-61 [b] E. R. Frederick, (MI '65)

[c] D. Wilson (J.T. I.'63) [@ 70°F/50%RH]

The critical influence of fabric finish on chargeability is evident in Table 5. Here an as-received commercial fabric was found to have an electrical resistivity of 8.3×10^9 Ω/□ as conditioned, a value clearly indicative of a material with antistatic features. These properties are verified by the low chargeability values obtained by the rubbing tests (previously described above) and by the high discharge rate (80%RH). When the same commerical fabric was washed and rinsed, the resistivity determined in the same manner increased to about 10^{12} Ω/□ and high levels of charging (vs. nylon and Darlan) occurred. The rate of charge loss also decreased to 25 percent in two minutes. Obviously, the washing removed an antistatic agent.

TABLE 5
ELECTRICAL VARIATION IN
SOME FABRIC FILTER MEDIA

Fabric		Resistivity, Ω/□ @80°F/39% RH		Relative ES* Properties•		
No.	Type	Conditioned	@RT after 150°F/16h	vs nylon v.	vs Darlan v.	2-min Loss, %
18	p.e., sp & nap as rc'd	8.3×10^{9}	7.4×10^{13}	-1.3	+3.9	80
18	p.e., sp & nap washed & rinsed	2×10^{12}	5×10^{14}	-10.0	+11.6	25

*ES = Electrostatic • @ 70°F/50%RH

Further experimentation, in which the as-received fabric was heated at 150°F for 16 hours, indicated that the antistatic agent was also removable by heating. The slight improvement in resistivity shown by heating the laundered fabric simply indicates that the wash treatment was quite effective. Evidence such as this, reinforced by additional studies, suggest that the most common finish of concern on commercial filter fabrics is residual producer's finish, which is probably a quaternary compound used to enhance processing. Not only is this additive fugitive upon heating but it is also possible that it might pass through an intermediate amine decomposition stage that is extremely electropositive. It should be apparent that such variations in fabric surface conditions and the resulting influence that they have on electrical properties can, and most often do contribute to profound differences in filtration performance.

Particulate Resistivity

Variations in the electrical resistivity of some particulates are shown in Table 6. The results indicate that resistivity is a function

TABLE 6
ELECTRICAL RESISTIVITY OF SOME PARTICULATES

Particulate	Temp., °F	RH%	E,V.	I, amp.	R, Ω	Resistivity $\rho = 15.71R$, Ω-cm
Elec. Furnace, UD-A	70	35	-	-	-	6.5×10^{8}
" " "	200	v. low	-	-	-	1.2×10^{13}
S.S. Elec. Furnace, U-1-c	73	33	1470	2.3×10^{5}	6.4×10^{7}	1×10^{9}
Flyash, WP-S.A	73	33	72	1.35×10^{-2}	5.3×10^{3}	8.4×10^{4}
Ferromoly. b.p., C-L-A	73	33	1490	0.59×10^{-4}	2.5×10^{7}	4×10^{8}
Moly-met, R-S-A	73	33	1480	0.52×10^{-4}	2.8×10^{7}	4.4×10^{8}
P-6140 resin A	73	33	1480	$<10^{-12}$	$>10^{15}$	$>10^{15}$
Steel Burning Dust-R-C-A	78	55	1000	4.2×10^{-7}	2.4×10^{9}	3.8×10^{10}
Steel Grinding Dust-R-C-A	78	55	-	-	2.0×10^{7}	3.1×10^{8}

of temperature. These and other characteristics of particulates are described in more detail in Volumes I and II of the full reports.

PARTICULATE AGGREGATION

Thus far in this discourse only the electrical properties of collecting media and of collected particulate have been considered. The beneficial effects of a suitable balance between the electrostatic properties of the fabric and particulate, according to my interpretations and now supported by Professor Penney's studies, is in the porous nature of the deposited cake.

When the particles in an aerosol entering and leaving the fabric filter, especially a medium with favorable collecting properties are compared, very interesting and significant differences are found (refer to Figures 1 and 2). It is evident from these photographs that a transformation occurred from a condition of finely dispersed particles to masses of large aggregates or agglomerates. This observation is critically important since it indicates a change from a kind of particle distribution that would pack tightly into a highly flow-resistant cake to a porous, low resistance (air-flow) kind of deposit. Repeated verifications of this change, occurring to a significant extent only when media of certain electrostatic features were used, led to the hypothesis that many particulates could be agglomerated on certain filter surfaces. A study conducted by Professor Penney and described more fully in Volume I of this series, provided the first real proof that particulates could be selectively aggregated to form a porous deposit on a "preferred" medium. When he passed corona charged (electronegative) dye particles into a wool/acrylic fiber filter, only the electropositive wool fibers collected the particles. Furthermore, these were deposited as a porous, chain-like aggregate (refer to Figure 3). This, by far, is the most important basis for claiming the interactions and attendant benefits in filtration parameters attainable by favorable electrostatic balancing between a filter medium and the particulate. This phenomena, then, should hold whether the electrical influence is achieved by natural charging or "artificially" by electrical augmentation.

SOME EXPERIMENTAL FILTRATION STUDIES

Flyash Collection (Table 7)

During the shake-down operations carried out on the experimental filtration equipment, a comparative study was made using several different fabrics to collect flyash. Since the evaluation was carried out at ambient conditions, the results should not be viewed as being directly related to actual field conditions. It is interesting to note, however, that the fabrics #40, #42, and #41 in the middle region (-0.3 to +2.0) of the triboelectric series that also develop the highest level of charge, collect the largest quantities of flyash before reaching the accepted pressure drop limit of 6 in. w.c. (The apparent good collectability of fabric #44, a filament yarn product, must be discounted because of its high leakage.)

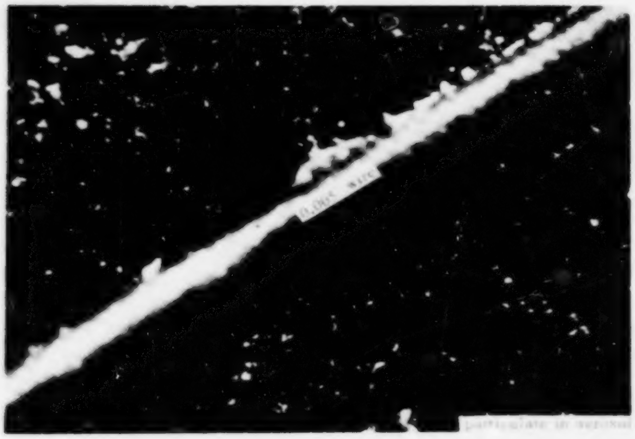
0.005 wire
particulate in aerosol

FIGURE 1 FERROMOLYBDENUM BY-PRODUCT DUST FILTER

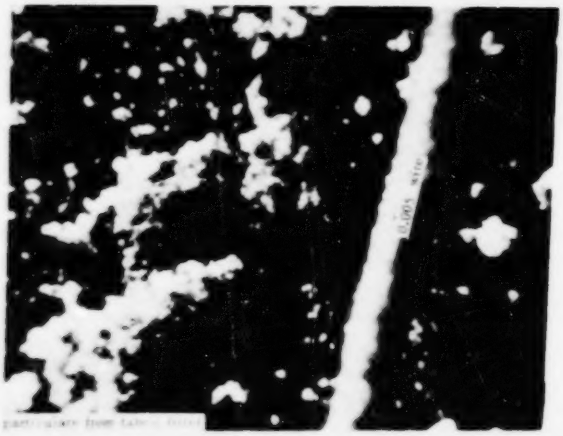
0.005 wire
particulate from fabric filter

FIGURE 2 FERROMOLYBDENUM BY-PRODUCT FILTER

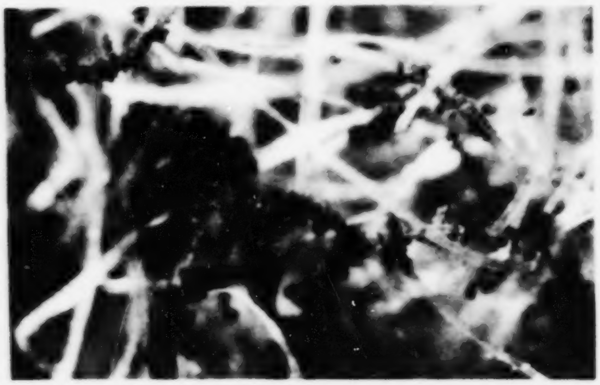

FIGURE 3 NEGATIVELY CHARGED PARTICLES AGGREGATED ON POSITIVE FIBERS

TABLE 7

EXPERIMENTAL FILTRATION OF FLYASH, WPP-S

[A/C =5.4, ΔPc limit =6 in. w.c., @ 75°-85°F (∿60%RH), Shake Cleaning]

Fabric					Filtration Parameters			
No.	Yarn	Fiber	Perm.	TE Position Total rub v	Collected Solids, g	Plug Wt. g.	Plug ΔP in W.C.	Relative Leakage
21	sp	wool/nylon	35	+8/11	120	48	2.6	v. low
28	tex. fil.	glass	48	+5/-	175	31	1.2	low
15	fil.	Da p.e.	39	+4.8/10.8	130	20	1.8	m. high
40	sp.	Dr acr.	35	+2/20.8	240	8	0.5	v. low
44	fil.	p.p.	20	-2.7/7.6	230	17	1.0	v. high
42	sp.	Or acr.	42	-0.3/13.3	230	16	0.8	v. low
41	sp.	Ze acr.	28	-0.3/15.8	200	26	1.0	v. low
37	fil	Tef.	21	∿-6/11.5	195	16	1.4	m. high

Further speculation suggests that electrostatic differences explain plug weight and plugged cloth pressure drop variations. These three fabrics, all acrylic but made from different types of fiber, yet similar in construction, provide distinctly different plugged cloth data. The #40 bag retains only 8 grams of flyash and shows the lowest pressure drop and highest collectability all without significant leakage. The indication is that the cake is not only more porous as collected but that it is also more easily removed by the adopted cleaning practice.

METALLURGICAL DUST COLLECTIONS

Electric Furnace Dust

Fabric filtration has become a popular and effective procedure for controlling the emissions from electric furnaces. Most often a bag filter is used to control the emissions of an entire electric furnace shop. These, therefore, are large installations, requiring the processing of vast quantities of dust-loaded air. In one installation, almost 5500 large (34 ft. long by 11 3/4 in. diameter) bags collect the particulate from 1 3/4 million cfm of aerosol from an electric furnace shop. The in-service bags are made of filament yarn polyester fabric and operate at a pressure drop of 8 to 9 in. w.c. before cleaning. Suspecting that this level of resistance was excessive, too energy intensive and contributing to the high operating cost, an experimental study was conducted using the laboratory filter unit.

Figure 4 compares the results of an initial screening test on three polyester bags used for collecting this electric furnace dust at 150°F. Quite obvious differences in performance are evident. The test fabric (filament) of the same general type used in the industrial baghouse, tended to short-cycle while the other two test media performed better and one of them (fabric #18) displayed especially favorable properties. While all three fabrics are polyesters of essentially equal permeability, major differences are evident in their triboelectric location and in the magnitude of charge that they generate.

Additional comparative filtration studies were carried out by comparing fabric #18 and seven other fabrics selected for construction similiarities but made from two acrylic, other polyester and Nomex fibers. While the outstanding performace of the napped polyester fabric (#18) was verified, comparable or better results were obtained with one of the acrylics. This fabric also provided good collectability but because it was not napped, it accumulated less plug. Quite significantly the favorable acrylic was located at a triboelectric position of +2 compared to +1.4 for fabric #18 and had a total rub voltage of 20.8 compared to 21.6 fabric #18. These similarities in electrostatic polarity and charge magnitude for the two effective filter media, even though of different fiber make-up, are considered to support the contention that only certain critical electrostatic features favor these conditions that lead to superior filtration performance.

CONDITIONS - A/C = 5.4, ΔPc limit = 6 in. w.c., 150°F, shake (moderate) cleaning

LEGEND:	Run No.	Fabric No.	Fabric Type	Fabric Fiber	Fabric Perm.	Plug Wt. g	Rel. T.E. Position Total Rub Voltage
———	41	16	fil.W/fil.F	Da 55/Da 58 & Si.	36	3.6	-2.5/8.8
- - - -	40	15	fil.W/sp.F	Da	39	9.7	+4.8/10.8
········	42	18	sp.W/sp.F	p.e. & nap.	38	26.9	+1.4/21.6

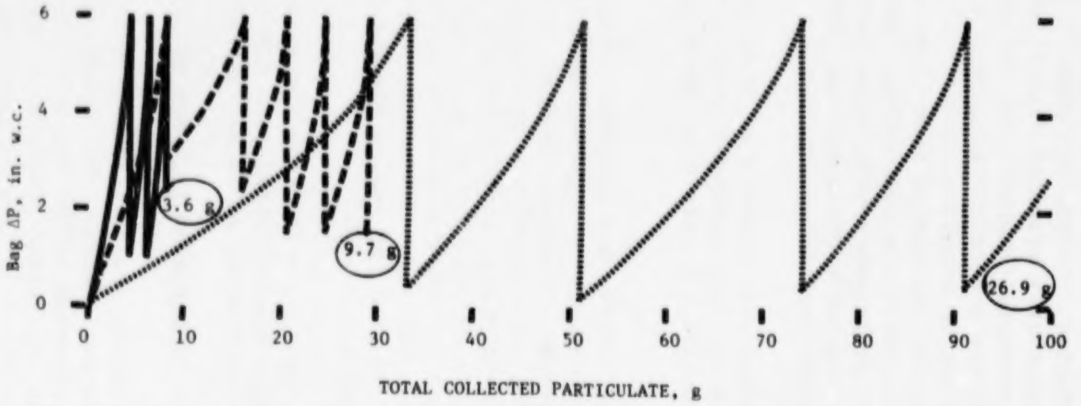

FIGURE 4 EXPERIMENTAL FILTRATION OF ELECTRIC FURNACE DUST,

STAINLESS STEEL ELECTRIC FURNACE DUST, U-J

Prompted by reports of collection problems with a stainless steel electric furnace dust, possibly related to electrostatics and reflected specifically by abnormally high pressure drop in an industrial, shaker-type baghouse, a filtration study involving at least twenty different media was conducted. Initially, comparisions were made of the more popular and relatively standard filter fabrics, but later other woven fabrics were examined together with knitted materials. The results indicated that the moderately electronegative and high charge intensity media such as napped acrylics, napped cotton and napped polypropylene (in this order for increasing effectiveness) performed better than a variety of relatively electropositive fabrics (nylon, polyester, and wool). Better performance was judged largely by better collectability as the test bags reached a pressure drop limit of 6 in. w.c. under equilibrium conditions at an A/C of 5.4.

The acrylics were considered to be the preferred practical choice for industrial service, inasmuch as problems could develop with the otherwise effective but more heat sensitive polypropylene and cotton media.

A knitted acrylic was found to collect the dust quite well and surpassed the performance of a polyester knit fabric. However, it was not acceptable because of excess leakage. A lower permeability (<30) knit fabric provided as a substitute by a vendor was a bluish-grey fabric and displayed extremely high electropositive properties. Actually this knit acrylic was as positive as nylon and definitely not like conventional acrylics in the triboelectric series. After proving in filtration tests that this was not a favorable medium for collecting the ssef dust, it was rejected for use in the plant baghouse in deference to a specified acrylic.

The U-J baghouse collecting the emission from this stainless steel electric furnace was reclothed with the recommended medium in May 1977 and has been functioning quite satisfactorilv at a ΔP of 3.5 in. w.c.

THE COLLECTION OF A FERROMOLYBDENUM BY-PRODUCT, CM-L

The filtration study of this ferromolybdenum by-product (fmbp) was carried out in two stages. The results are considered here essentially as they were reported at the end of each stage to demonstrate that in the course of such evaluation programs, a representative variety of media should be examined. It is also important that more than the common physical properties of the media and particulates be considered. Reliable interpretations of performance differences cannot be accomplished with just the usual information on fiber type, fabric construction, permeability, and weight together with the usual particulate parameters of size and chemistry.

For the first five fabrics evaluated for collectability with this dust, the major differences in performance were attributable as much or more to construction variations (i.e. filament vs. spun yarns) as to differences in electrical properties. Three spun yarn fabrics, whether of 50 to 21 permeability, provided high collection efficiency mostly because thev retained a high level of dust (after cleaning) that served as a filter-aid. The filament yarn fabrics on the other hand, retained less dust, were inherently less bulky, and leaked the dust quite seriously throughout the entire filtration cycle, but most seriously at start-up. The filament type fabrics retained one tenth or less as much plug as the spun yarn fabrics. However, they exhibited about the same air flow resistance according to the plugged cloth pressure drop values. Obviously, the dust residues in the two types of media differ in porosity.

In subsequent filtration studies of the ferromolybdenum by-product dust, (fmbp), five other fabrics were evaluated. The results are summarized in Table 8. From these trials as well as from the rolling tests carried out on the dust, it became evident that this fmbp particulate agglomerated quite easily, especially in contact with the more electropositive, high charge intensity fabrics. As a result, the media that perform best are those that provide these properties. The electropositive fabrics #102, #144, and #111, perform well despite high electrostatic discharge rates, whether such rapid dissipation is achieved by means of a conductive (graphite) finish or provided naturally as in cotton. The highly electropositive media seem to be more effective than those that are electronegative fabrics, in promoting agglomeration of this dust.

The addition of a high discharge rate finish does not detract from the performance of an otherwise favorable (electropositive) fabric, #144. On the other hand, neither the slightly negative material (acrylic as in the #120) nor a very electronegative fabric (Teflon #37) perform well, despite favorable construction features. However, when the electropositive requirements are satisfied, then suitable construction and high electrostatic discharge rate features seem to further improve performance. [Incidentally, antistatic features do not eliminate charging but only insure fast charge bleed-off.]

POLYMERIC DUSTS P·K-3085 AND P·6140

Two polymeric dusts were submitted for examination because of commercial filtration problems, especially with dust retention. Both dusts are flammable, thermoplastic and develop high levels of electrostatic charge. Resistivity measurements at 70%F/40%RH also indicated that both dusts had values greater than $10^{14}\ \Omega/\square$. In the rolling test, the apparent density of P·K-3085 increased by about 13.7% and that of P·6140 increased by 9%. Both show evidence of aggregation.

The filter test results, although limited to an evaluation of seven media [three very electropositive, three electronegative and a moderately positive fabric (refer to Tables 9 and 10] permit some tentative conclusions of practical significance. While both of these polymeric dusts show the same high level of electrical resistivity $(>10^{14}\ \Omega/\square)$, they differ appreciably in their aggregating and filtering properties. Of the two dusts, the P·6140 resin is the most critical, in regard to its tendency to agglomerate and with repect to its overall collectability. With P·K-3085 dust, all but the plant-used fabric (Teflon) performed well without leakage. The more critical-to-collect P·6140 dust is filtered best without leakage only by the high charging electropositive fabrics.

It is especially interesting to note that the very electronegative Kevlar fabric #65 performs only slightly better than the other electronegative filters, including the plant-used Teflon #94. Actually, the Kevlar filter performed more like the Teflon and Gore #89 fabrics in regard to collected solids, plug retention, and plugged cloth resistance than the electropositive fabrics. In collecting the P·6140 dust, therefore, the more electropositive, high charging media perform far better than the electronegative materials. The outstanding performance of the high charge, only moderately high electropositive polarity, low dissipation rate polyester fabric #18 with this dust is noteworthy. From these data, it seems clear that for collecting the P·6140 dust without leakage, the preferred medium is electropositive but not necessarily at the top level in the triboelectric series, capable of generating a high intensity of charge and with a relatively low rate of charge bleed-off. These features, presumably, are effective in encouraging suitable aggregation of the P·6140 dust on the collecting fabric. The same fabric should also be effective in collecting the P·K-3085 resin even though it seems to respond favorably to the lesser extremes in charging.

THE COLLECTION ON SILICA PG-C

Only a few particulates seem to resist aggregation and fail to respond to electrostatic charge induced agglomeration on a suitable filter medium. While silica does agglomerate, it seems to reach a state of limited aggregate stability. In fact, in the rolling test arbitrarily adopted as a guide to indicate whether or not dusts will agglomerate, silica (at least the two varieties examined) actually seems to desperse somewhat into more "feathery" aggregates and consistently showed a reduction rather than an increase in density. In the collection of silica by fabric filtration, therefore, agglomeration beyond a frail aggregate structure cannot be relied upon for optimizing filter performance. Fabric selection to realize the best performance seems possible on the basis of other operating parameters.

Since extended processing may tend to further disperse silica and almost any commercial method of handling this material can be expected to induce such a change, selection of the preferred medium will most

TABLE 8

EXPERMENTAL FILTRATION OF A FERROMOLYBDENUM BY-PRODUCT DUST, CM-L

[A/C =6, ΔPc limit = 6 in. w.c., 130°F, 3-5 gr/ft^3 loading, shake cleaning]

FABRIC						FILTRATION PARAMETERS			
							Plug		
No.	Type	Fiber	Perm.	TE Pos.	2 min. Loss, %	Collected Solids, g	Wt. g.	ΔP in.	Relative Leakage
102	sp	wool	50.5	+5.5	85	16	45	0.6	low
120h	sp	acr. & as.	50	-1	100	4	80	2.2	low
120i	sp	acr. & gr.	50	-1	100	11	60	1.0	low
144c	sp	wool/nylon & gr.	50	>+6	100	22	40	0.5	low
144a	sp	wool/nylon	50	>+6	80	19	65	0.9	low
111	sp	cotton	17.5	very +	100	18	60	1.0	low

TABLE 9

EXPERIMENTAL FILTRATION OF A POLYMERIC DUST, PK-3085

[A/C = 6; ΔPc limit = 6 in. w.c., 70°-75°, shake cleaning]

FABRIC					FILTRATION PARAMETERS			
						Plug		
No.	Fiber	Perm.	Res. Ω/□	TE Pos. Total V.	Collected Particulate, g.	Wt. g.	ΔP in W.c.	Relative Leakage
71	wool sp.	46	10^{13}	+5.6/8.3	171	15.6	0.15	low
94	Tef fil.	37	$>10^{14}$	-6 /11.5	148	1.4	0.7	m. high
89	Gore/p.e.	19.5	$>10^{14}$	-3.6/16.8	207	9.3	0.7	low
96	wool/nylon	102	2.9×10^{13}	+5.7/12.2	190	30	0.1	slight
78	wool/nylon	33	4×10^{12}	∿+7 /11.3	193	9.3	0.2	low
18	p.e., sp & nap	38	$>10^{14}$	+1.4/21.6	230	12.6	0.1	low

TABLE 10

EXPERIMENTAL FILTRATION OF A POLYMERIC DUST, P-6140

[A/C = 6; ΔPc limit = 6 in. w.c., 70-75°F, shake cleaning]

FABRIC					FILTRATION PARAMETERS			
						Plug		
No.	Fiber	Perm.	Res. Ω/□	TE Pos. Total v.	Collected Dust, g.	wt. g.	ΔP in.	Relative Leakage
96	wool/nylon	102	2.9×10^{13}	+5.7/12.2	130	33	0.35	sl (cleaning)
78	wool/nylon	33	4×10^{12}	∿7 /11.3	113	12.4	0.4	low
78a	wool/nylon	33	10^{8}	(∿7/11.3)a.s.	102	13	0.5	low
18	p.e. sp. & nap	38	$>10^{14}$	+1 / 21.6	124	15	0.2	low
89	Tef. lam./p.e.	19.5	$>10^{14}$	-3.6/16.8	88	8.4	0.7	low
94	Tef.-fil.	37	$>10^{14}$	∿-6 /11.5	71	6.2	1.2	v. high
65	Kev.-fil.	31	10^{14}	∿-8 /18	96	5.4	0.8	high

TABLE 11

EXPERIMENTAL FILTRATION OF SILICA, PG-C

[A/C = 6, ΔPc limit = 6 in. w.c., 130°-140°F, shake cleaning]

FABRIC						FILTRATION PARAMETERS			
							Plug		
No.	Yarn	Fiber	Perm.	TE Position Total rub v.	2 min. Loss, %	Collected Particulate, g.	wt. g.	ΔPp	Relative Leakage
97	sp	wool/nylon	76	∿+8 /18.1	80	125	60	0.6	m. low
109	sp (felt)	Da., p.e.	56	-2.8/17.6	30	105	45	0.3	m. low
16c	sp	Da., p.e.	26	-2.5/ 8.8	30	22	5	0.9	high
55	sp (felt)	Dar., acr.	32	-3.7/15.7	30	40	45	0.3	low
65	fil.	Kev.	31	∿-8 /18	45	130	21	0.6	high

likely have to be directed more to attain and maintain a high level of efficiency than to realize an exceptionally low operating pressure drop. In other words, fabric construction would seem to have to be relied upon primarily to achieve a good pressure drop-collection relationship. But the electrostatic properties of the medium might be used to hold an effective filter-aid like cake on its surface at all times and, thereby, enhance efficiency. This suggests that the polarity difference between the dust and the filter medium should be high in order to offer substantial attraction between the two materials and. further, that the discharge rate of the fabric be sufficiently low to maintain the attractive forces for an adequate period of time. These conditions will keep some of the dust on the surface of the fabric, even after the cleaning operation. Obviously, cleaning effectiveness may also have to be sacrificed and, in fact, controlled at less than a maximum level.

According to the data reported earlier (Table 3 provided by Professor Penney) silica should be located at about -3, between -2.5 and -3.6 on the arbitrary scale of our triboelectric series. In this location, a considerable electrostatic influence should be exerted on silica dust by a highly positive fabric like #97 (wool/nylon) or bv a highly electronegative fabric like #65 (Kevlar), both of which are widely separated from the silica in the T.E. Series. In a favorable construction, the wool/nylon and a Kevlar fabric might be expected to perform similarly, filtrationwise (refer to Table 11). The Kevlar fabric, however, displays a higher rate of charge dissipation (45% in 2 min. compared to the 20% value shown for the wool/nylon materials). More serious, though, is the significant difference in the bulkiness of the two materials with the filament Kevlar fabric offering little more than the screen-like properties compared to the high bulk, good cover, high charge features of the wool content medium. On all counts, then, the woven wool/nylon #97 should perform at high collection efficiency in shaker-type cleaning systems, and a felted wool should be best in a pulse collector.

Certainly compared to the filament yarn fabric or even the woven wool/nylon fabric, the data recorded for the felt fabric #109 are most striking. Despite the fact that bags made of felt-like materials do not shake as well as the more flexible woven fabrics, the plugged cloth pressure drop value (ΔPp) for the polyester felt increased from an initial value of 0.1 in. to only 0.3 in. w.c. and the plug weight, again despite the fabric's comparatively very high bulk, increased from about 30 to only 45 g. This level of plug weight, although seemingly somewhat elevated, is really relatively low for a felt-like filter bag and yet it is below that found in the far more open (higher permeability), less bulky, wool/nylon bag of exactly the same filter area. In addition, compared to this polyester needled bag, the wool/nylon fabric collected about 15% more dust before reaching the same limiting pressure drop (ΔPp) of 6 in. w.c. Since some of this better collectability might be attributed to permeability difference, major emphasis must be placed on the plug weight and plugged cloth pressure drop data to provide a measure of evidence for the effectiveness of electrostatics in producing and retaining the attractive forces needed to form and hold a filter aid type of surface of silica on the fabric during each filtration cycle.

CONCLUSIONS

Many of the conclusions reached in the foregoing discussions relate electrostatic properties of filter fabrics with those of the particulates** to explain collectability, cleanability or efficiency are developed upon circumstantial evidence. But any other fabric or particulate property fails completely to offer a more reasonable explanation. The basic premise of the electrostatic involvement theory deals with particulate aggregation. Whereas this electrostatic charge-agglomeration reaction was first merely hypothesized, Professor Penney's work now removes some of the guesswork. His studies have demonstrated, for example, that "impact" charged particles form a "chain-like," porous or agglomerated deposit on a fabric without the use of high voltage either on the particulate or on the collecting surface. This observation serves to confirm the premise that natural charging can produce aggregates just as artificial charging (i.e. in an electrostatic precipitator) often leads to such a change in particulate qualities.

In another of Penney's tests,++ again without an external potential being impressed on the filter fabric, corona-charged particles (electronegative) also became deposited in a "chain-like" aggregated manner on just the electropositive fiber of a composite, two fiber filter. The fact that one fiber remained clean while the adjacent fibers and only these electropositive fibers. collected the negatively charged particles as a porous aggregate is viewed as supporting evidence for the effectiveness of high, often opposite charges in promoting the agglomeration of difficult-to-agglomerate particulates. (Refer to Figure 3)

**Frederick, E. R., "How Dust Filter Selection Depends on Electrostatics, Chem. Eng. 68:107, (1961).

Frederick, E. R. Some Effects of Electrostatic Charges In Fabric Filtration, J. Air Pollution Control Assoc., 24:1164 (1974).

++Penney, G. W., Collection of Electrically Charged Particles in Filters, J. Air Pollution Control Assoc., 26:58 (1976).

EPA IN-HOUSE FABRIC FILTRATION R&D

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ABSTRACT

This paper describes some of the work done at EPA's North Carolina research facility. Emphasis is given to showing that particle penetration through filter fabrics depends on different mechanisms for different dust/fabric/cleaning combinations.

INTRODUCTION

The purposes of the EPA in-house program are to:

maintain currency in fabric filtration work
perform fabric evaluations
do research in support of EPA priorities
support R&D being performed by contractors and grantees

This paper will describe some history leading to present work, and some recent results.

A LITTLE HISTORY

Prior to the formation of EPA in 1970, fabric filtration R&D was being performed by the Public Health Service (PHS). Their work included development of graphite coatings for glass bags, analysis of baghouse operation, investigation of fabric structure influence, and other types of laboratory research. Much of the work was done in-house rather than by contract with private enterprise.

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When EPA was formed, laboratory functions were transferred from PHS to EPA. As EPA's responsibilities increased, without a like change in Agency manpower, more and more work was performed under contract. About 90 to 95% of our funds (in the Particulate Technology Branch (PATB)) are now spent for contract, grant and interagency R&D.

Figure 1 highlights the major research areas up to 1978. Figure 2 shows in-house work scheduled or contemplated over the next year or two.

The in-house work is being reported as a series of publications entitled, "EPA Fabric Filtration Studies. No. __ : Subtitle." There are now six reports in the series (1-6). Particle penetration is the subject of Report No. 6, and will be discussed next.

PARTICLE PENETRATION

Figures 3, 4, and 5 show particle concentration vs time in the outlet duct of small pulse-jet or shaker baghouses operated in the PATB laboratory.

Figure 3 is for a shaker baghouse with 5 oz/yd^2 (170 gm/m^2), 3 X 1 twill, continuous filament polyester. Redispersed fly ash was fed to the house at 3 grains/ft^3 (6.9 gm/m^3), and an air-to-cloth ratio (filtration velocity) of 4 fpm (2 cm/sec). This figure shows that, starting immediately after cleaning, larger particles penetrate sooner, and in larger numbers, than smaller particles. Viewing the figure as one overall curve rather than three, there is the typical outlet concentration spike immediately after cleaning, and then a tapering off as the filtration period progresses. Figure 3 shows that, for these conditions, the baghouse segregates particles by size and with time.

Figure 4 shows something a little different. This figure is for a pulse-jet baghouse with 16 oz/yd^2 (542 gm/m^2) polyester felt. The test dust was rock dust fed at 11.9 grains/ft^3 (27 gm/m^3), and the air-to-cloth ratio was 6 fpm (3 cm/sec). In this figure the particle penetration peaks still exist, and the larger particles peak first (or more sharply). Compared to Figure 3 there is much more overlap of the peaks, the larger particles do not outnumber the smaller ones, and the total number of particles is much smaller (but the filtration time is much shorter, too). There are obvious similarities between the two figures, but there are also dissimilarities.

For further change, look at Figure 5. This figure is for the shaker baghouse with a polytetrafluoroethylene (PTFE) expanded film laminated to a woven aramid backing. Other operating conditions are the same as for Figure 3. In this case the fabric is far more efficient than the woven polyester, and also shows completely different penetration character. There is only a slight peaking for each particle size, and all sizes peak at the beginning of the filtration cycle. Penetration then remains nearly constant for the remainder of the cycle. For this fabric the particle concentration by size is reversed; the smallest particles penetrate in the largest numbers. Although not shown in the figures, pressure drop was also much lower for the PTFE/aramid than for the woven polyester.

The point to be made with Figures 3-5 is that particle penetration does not proceed by a single mechanism. There is more than one mechanism taking place; relative importance among the mechanisms depends at least on the dust fabric combination, and on the passage of time during the filtration cycle. Report No. 6 gives a further development of the mechanisms and compares EPA in-house results with those obtained by other investigators.

The work reported above will be continued, along with other topics as shown in Figure 2, as the in-house part of EPA's furtherance of fabric filtration technology.

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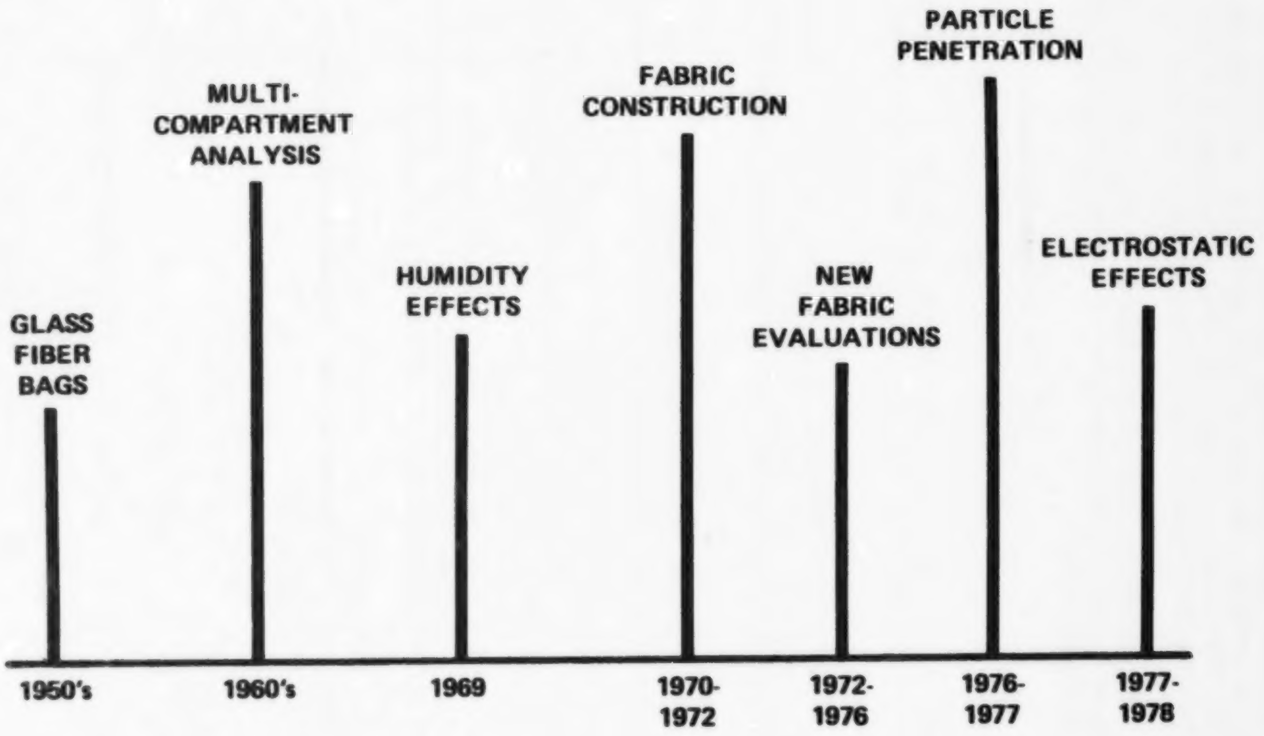
GLASS
FIBER
BAGS
MULTI-
COMPARTMENT
ANALYSIS
HUMIDITY
EFFECTS
FABRIC
CONSTRUCTION
NEW
FABRIC
EVALUATIONS
PARTICLE
PENETRATION
ELECTROSTATIC
EFFECTS
1950's
1960's
1969
1970-
1972
1972-
1976
1976-
1977
1977-
1978

Figure 1. Fabric Filter In-house R&D Done by EPA and Predecessor Organizations

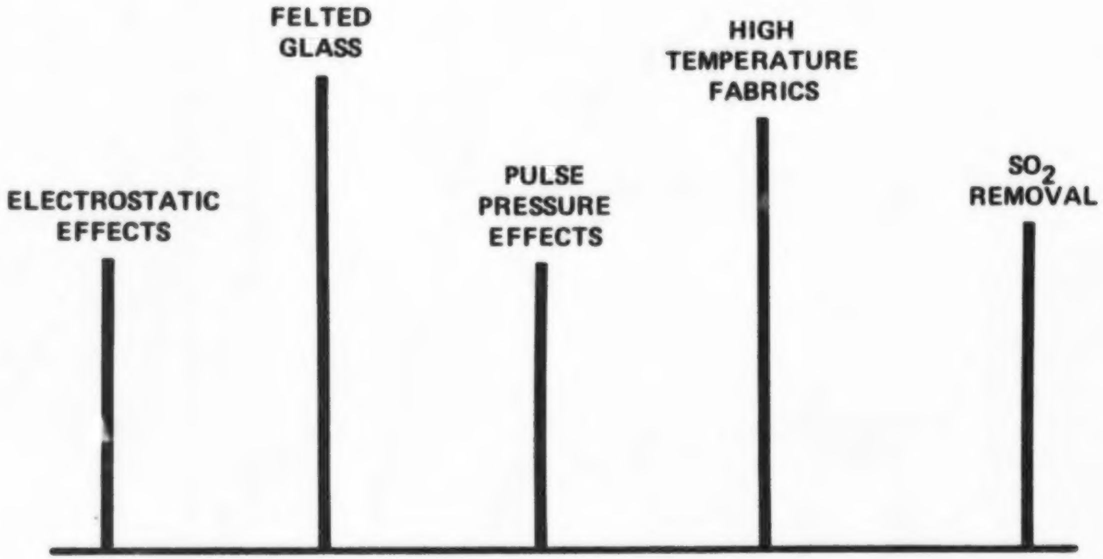
ELECTROSTATIC EFFECTS
FELTED GLASS
PULSE PRESSURE EFFECTS
HIGH TEMPERATURE FABRICS
SO_2 REMOVAL

Figure 2. Future R&D for EPA In-house Fabric Filtration

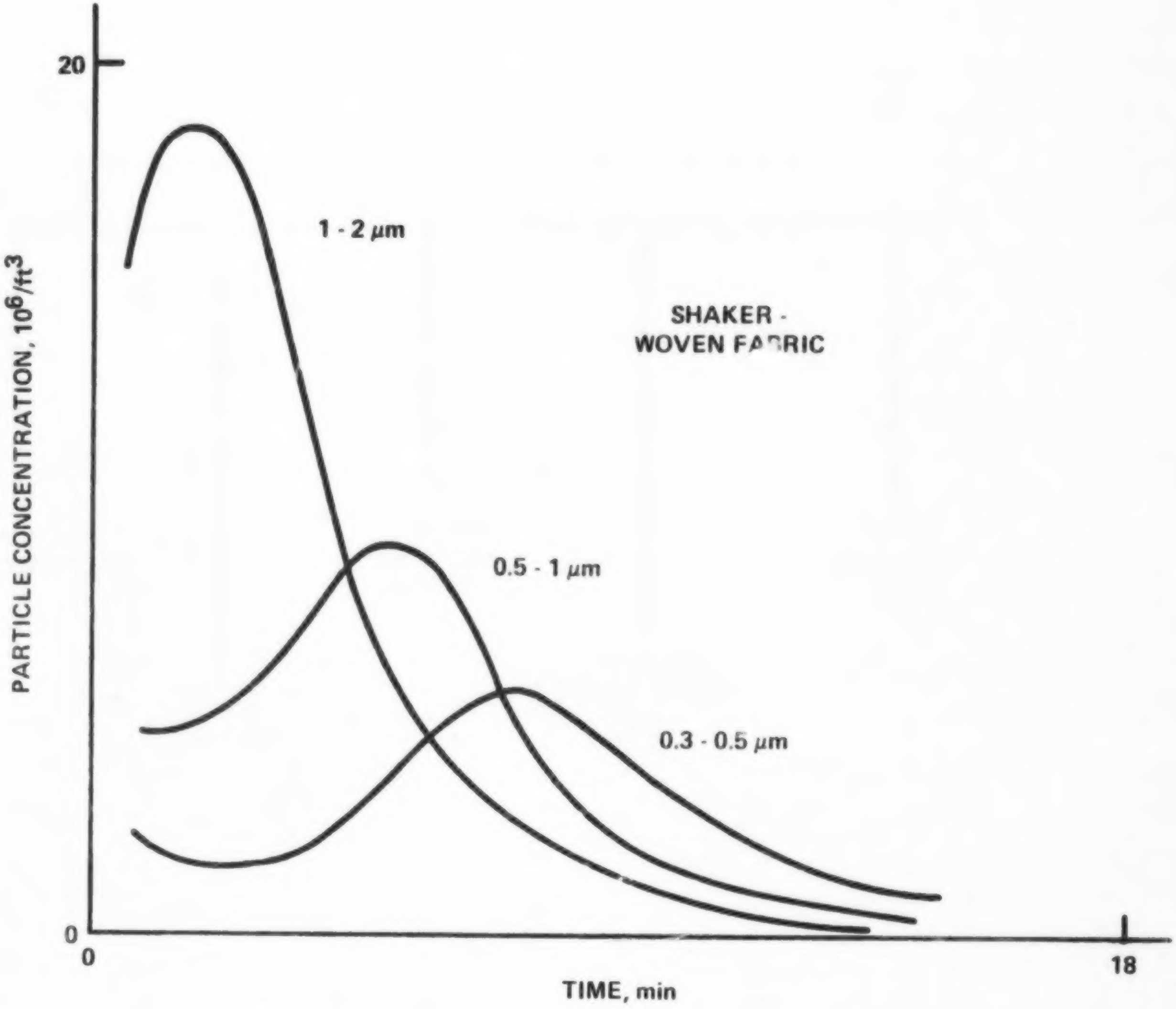

Figure 3. Particle Penetration (Flyash) for Shaker Baghouse with Woven Polyester

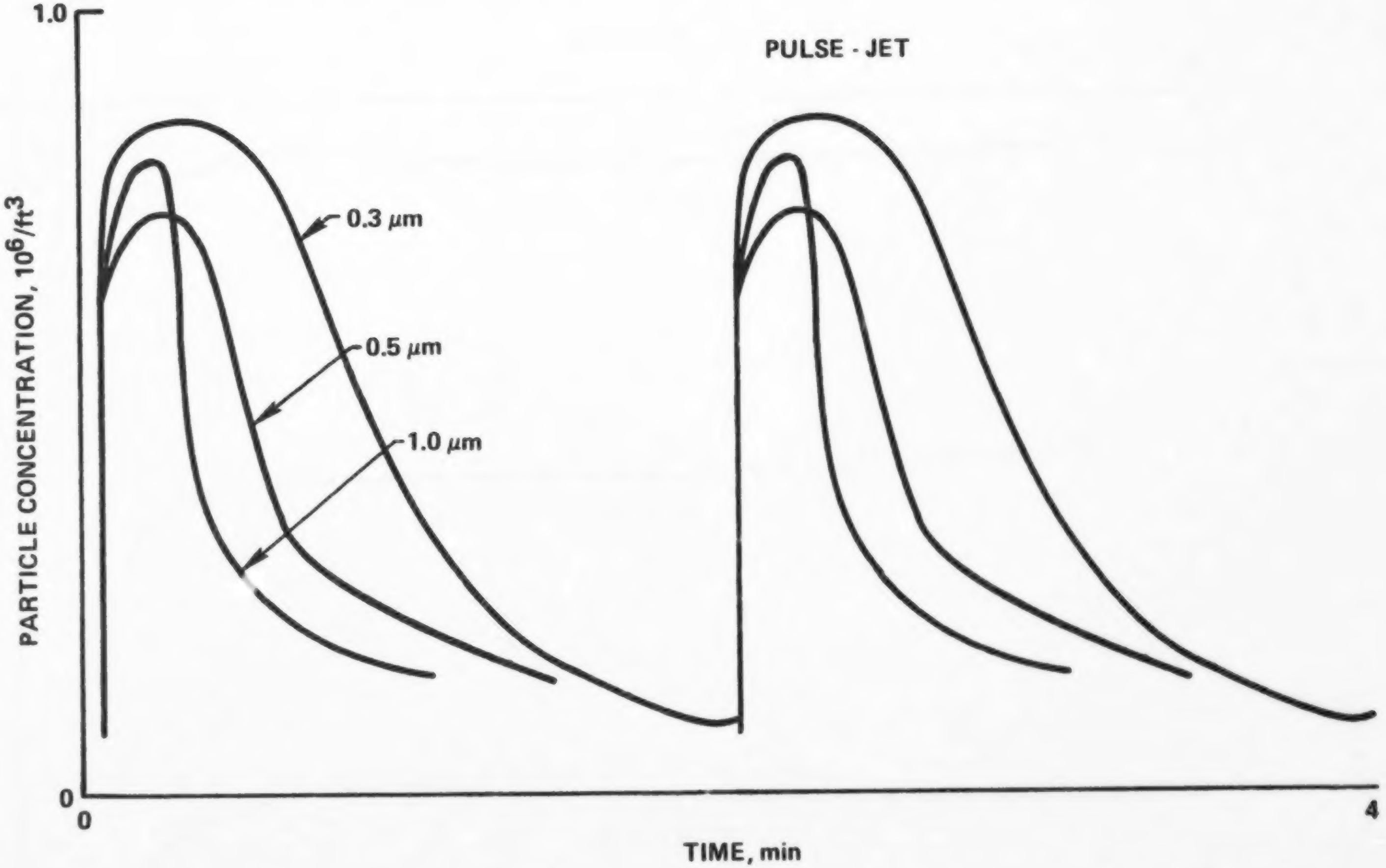

Figure 4. Particle Penetration (Rock Dust) for Pulse-Jet Baghouse with Felted Polyester

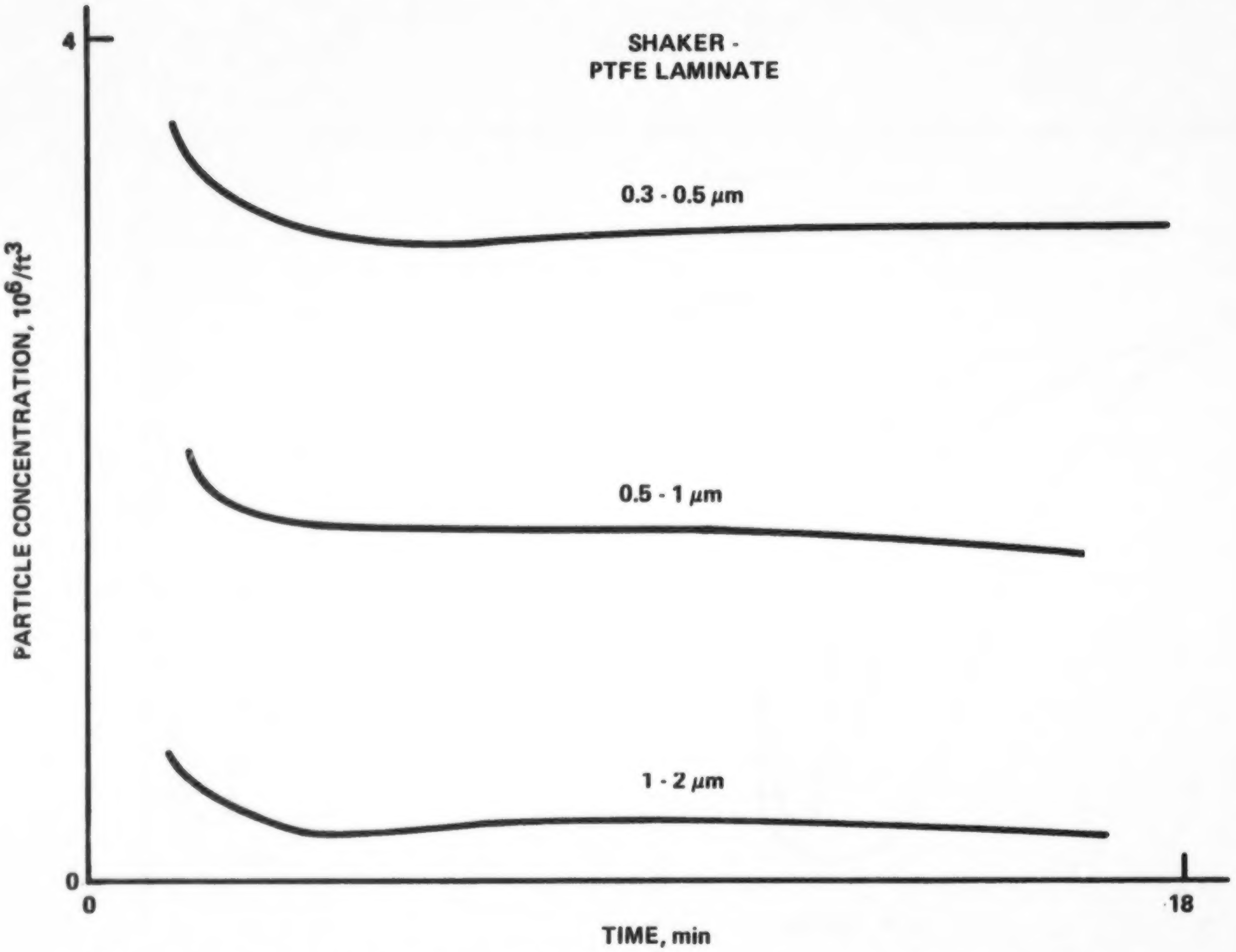

Figure 5. Particle Penetration (Flyash) for Shaker Baghouse with PTFE/Aramid Laminate

ENVIRONMENTAL PROTECTION AGENCY
FABRIC FILTER PROGRAM-
A COMPARISON STUDY OF UTILITY BOILERS
FIRING EASTERN AND WESTERN COAL

Bill Lipscomb
Energy & Environmental Division
Acurex Corporation

1.0 INTRODUCTION

The increased utilization of coal for process steam and electric power production accompanied by rising interest in low sulfur coal has directed attention toward inherent performance differences of electrostatic precipitators (ESP) as applied to Eastern and Western coals. Since an increased application of fabric filters to coal-fired boilers has also resulted, an investigation into inherent performance differences of fabric filters as applied to boilers firing Eastern and Western coal would seem logical. Insight into this question was achieved by using the U. S. Environmental Protection Agency (EPA) Mobile Pilot Baghouse, which allowed not only comparative operating procedures and testing methods, but also, and most importantly, an evaluation utilizing the same control device at different sites. This paper presents the preliminary results of a comparison study of a pilot scale fabric filter applied to pulverized coal-fired boilers burning an Eastern and a Western coal.

TEST OBJECTIVES

The objectives of the testing programs were:

- Comparison of mobile baghouse operating characteristics.
- Comparison of performance.
- Recommendations for further pilot plant testing.

Primary effects of interest were:

- Bag ΔP vs. Time.
- Mass and Fractional Efficiency.
- Temperature.

2.0 SITE DESCRIPTIONS

The Western coal study was conducted by Monsanto Research Corporation from May-July, 1977 at Southwestern Public Service Company's (SPSCO) Harrington Station in Amarillo, Texas.[1] Harrington Station Unit 1 is a 350 megawatt (MW) pulverized coal-fired boiler burning low sulfur, sub-bituminous Western coal from Wyoming.

The Eastern coal study was conducted by Acurex Corporation from February-May, 1978 at Michigan State University (MSU) Power Plant 65 in East Lansing, Michigan. Power Plant 65 consists of two (Units 1 & 2) 250,000 lbs./hr. boilers and one (Unit 3) 300,000 lbs./hr. boiler. The plant is an extraction generating facility burning pulverized bituminous Eastern coal from Kentucky. This facility utilizes nominal 900 lb. steam at 835°F for electrical power generation via turbines with the resulting 90 lb. steam being used for heating and cooling campus buildings.

The respective test sites are summarized in Table 1. The Eastern bituminous coal, as received, had an average ash and sulfur content of 14 and 0.75 percent, respectively. The sub-bituminous Western coal averaged 4.8 percent ash and 0.33 percent sulfur. This paper is not intended to be a comparison of typical Eastern and Western coals, but rather a comparison in which the control device, operating procedures, and sampling methodology are as identical as reasonably possible, leaving the two types of coal as the major variable between the testing sites.

Table 1. SITE DESCRIPTION

Eastern Coal	Western Coal
• Michigan State University Power Plant 65 - Unit 2 East Lansing, Michigan	• Southwestern Public Service Co., Harrington Station
• 250 x 10^3 lbs./hr.	• 350 MW
• Bituminous Coal	• Sub-bituminous Coal
• % Ash - 14 % Sulfur - 0.75 Btu - 12,000	• % Ash - 4.8 % Sulfur - 0.33 Btu - 8,600

3.0 DESCRIPTION OF EPA MOBILE FABRIC FILTER

The EPA mobile fabric filter was designed, fabricated, and originally operated by GCA/Technology Division.[2,3] Designed for the purpose of determining the effects of dust properties, fabric media, cleaning parameters, and other operating parameters on fabric filter performance, the mobile fabric filter system has the following capabilities:

- Filtration at cloth velocities as high as 20 fpm with a pressure differential up to 20 inches of water, and at gas temperatures up to 530°F.
- Adaptability of mobile system to cleaning by mechanical shaking, pulse jet, or low pressure reverse flow with cleaning parameters varying over a broad range.
- Utilization of 1-7 filter bags of any media, 4-10 feet in length, and up to 21 inches in diameter.
- Continuous 24-hour operation with use of automatic instruments and controls.

The mobile fabric filter is shown schematically in Figure 1.

4.0 MOBILE BAGHOUSE INSTALLATION AT MSU

Installation of the mobile baghouse was similar at both sites with respect to slipstream location, sampling nozzle, and required slipstream duct length. A plan view of the MSU installation is given in Figure 2. As at the Harrington Station, the slipstream take-off at MSU was located downstream from the air preheater and upstream from the mechanical collector which preceded the ESP. The slipstream duct, composed of 2.5-inch ID stainless steel tubing was 100-120 feet long at both sites.

To minimize condensation during start-up, the slipstream duct and baghouse were preheated. A preheat assembly, shown in Figure 2, was installed at the end of the slipstream duct nearest the plant. The preheat assembly was equipped with manual shut-off gates as well as gaskets for sealing and isolating the baghouse from the plant flue gas during preheating and non-operating periods.

5.0 TEST PROGRAMS

As has been stated the test procedures and methodology employed at the MSU testing site were chosen not to optimize system performance, but to duplicate as nearly as possible those employed during the earlier Harrington Station studies. This restriction resulted in several problems which will be mentioned later in this paper.

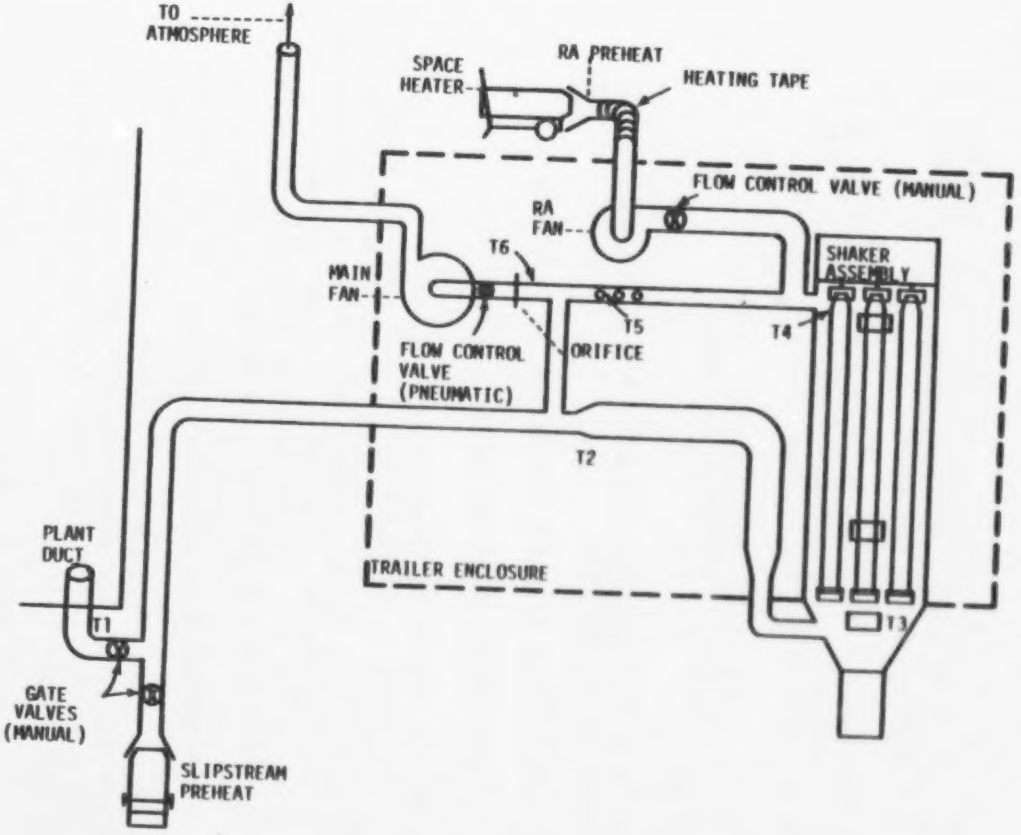
TO ATMOSPHERE
SPACE HEATER
RA PREHEAT
HEATING TAPE
FLOW CONTROL VALVE (MANUAL)
RA FAN
T6
MAIN FAN
SHAKER ASSEMBLY
T5
T4
FLOW CONTROL VALVE (PNEUMATIC)
ORIFICE
T2
PLANT DUCT
TRAILER ENCLOSURE
T1
T3
GATE VALVES (MANUAL)
SLIPSTREAM PREHEAT

Figure 1. Mobile baghouse schematic

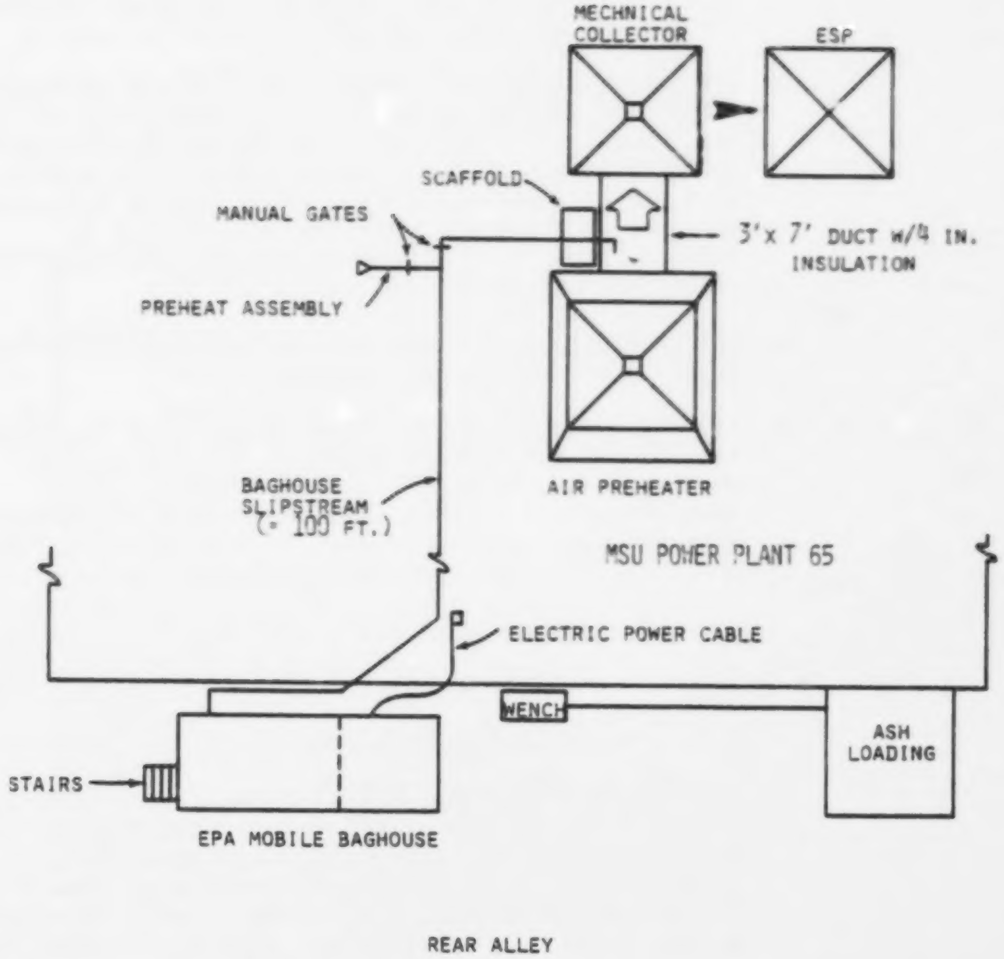
MECHNICAL COLLECTOR
ESP
SCAFFOLD
MANUAL GATES
3'x 7' DUCT W/4 IN. INSULATION
PREHEAT ASSEMBLY
AIR PREHEATER
BAGHOUSE SLIPSTREAM (≈ 100 FT.)
MSU POWER PLANT 65
ELECTRIC POWER CABLE
WENCH
ASH LOADING
STAIRS
EPA MOBILE BAGHOUSE
REAR ALLEY

Figure 2. Plan of mobile baghouse installation

BAGHOUSE OPERATING PARAMETERS

A summary of the baghouse operating parameters used for both studies follows:

- Bag Materials-Two bag materials were tested. The first was a Teflon-coated glass fabric (T/G) purchased from Menardi-Southern, and the second was a graphite- and silicone-coated glass fabric (G/G) purchased from W. W. Criswell Company. Bag manufacture was identical for both shake and reverse air bags with the exception of three spreader rings sewn into the reverse air bags to prevent bag collapse. Manufacturer specifications for the two bag materials are presented in Table 2.

- Air-to-Cloth Ratio-All baghouse testing was performed at an air-to-cloth ratio (or face velocity) of 3.0 fpm (15.5 mm/sec.). This ratio was originally selected to approximate the ratio planned for full scale baghouses at Harrington Station Units 2 and 3. Three bags were employed with a total effective area of 26.2 $ft.^2$ (2.43 m^2) and the flow rate in the bag compartment inlet was maintained at 80 acfm (0.0378 am^3/s).

- Bag Conditioning-All bags were conditioned for 24 hours prior to any performance testing.

- Bag Cleaning-Both bag materials were tested in shake and reverse air cleaning modes. Bags were cleaned when bag ΔP reached 4.0 in. (102 mm) H_2O. This value was chosen to duplicate the maximum bag pressure drop for the baghouses planned for Harrington Station Units 2 and 3. Shake cleaning parameters were:

  Shake Motor Speed - 6.9 cps.

  Shaker Arm Amplitude - 0.875 in. (22.2 mm).

  Shake Time - 10 sec.

  This resulted in a shaker arm acceleration of 4.3 g's and 138 shakes (2 per cycle) per cleaning duration. Bag tension was not measured, but was estimated at 1-2 lbs. (0.45-0.91 kg.). A 1-minute delay was used between filtration and shaking, and a 2-minute delay was used between shaking and filtration. Reverse air cleaning parameters were:

  Reverse Air-to-Cloth Ratio - 5.3 fpm [0.0269 m/s] (Maximum available from reverse air fan at operating conditions.)

At the onset of the earlier study on Western coal, the reverse air-to-cloth ratio was 2.0 fpm (0.0102 m/s). However, bag blinding was apparently encountered and the reverse air-to-cloth ratio was ultimately raised to the maximum. The reverse air time sequence was: first delay-minimum, with reverse air fan on and reverse air time of 30 sec; second delay-1 minute, with reverse air fan shut off at about 30 seconds.

Table 2. BAG MATERIALS TESTED

	Graphite and Silicone-Coated Glass Fabric	Teflon-Coated Glass Fabric
Weight, g/m^2	356	332
oz/yd^2	10.5	9.5
Thread Count	66 x 30	54 x 30
Weave	3 x 1 twill	3 x 1 twill
Permeability, $m^3/s/m^2$	.44	.38
cfm/ft^2	86	75

6.0 SAMPLING PROCEDURES

Sampling procedure and methodology were in general accordance with those recommended by current practice. Inlet and outlet total particulate mass concentrations were measured by 47 mm mass filters, and Brinks and Anderson impactors were used for particle sizing at the inlet and outlet points, respectively. Sulfur dioxide (SO_2) spot checks were made with detector tubes. Dry molecular weight was measured by the Fyrite method. Flyash samples were taken whenever the hopper was emptied, which was essentially a daily operation.

For a more detailed explanation of sampling equipment and methodologies, the reader is referred to "Mobile Fabric Filter Unit at SPSCO's Harrington Station, Amarillo, Texas (Technical Operations Report No. 5)."[3]

MOBILE FABRIC FILTER OPERATION

The reader is also referred to the above report for details regarding the operation of the mobile baghouse, i.e., probe location, leak checking, start-up and shutdown, flow rate control, bag cleaning, and data recording. It is not within the scope of this article to present detailed methodologies for the above procedures.

7.0 TEMPERATURE PROFILES

As stated previously, the necessity for duplicating the procedures, methodology, and operational characteristics of the mobile baghouse at both sites raised several problems. One such problem was temperature control. Temperature profiles across the pilot baghouse system, presented in Table 3, are remarkably similar, with outlet testing at both sides being conducted over essentially the same temperature range. However, these temperature profiles are not representative of actual (full scale) facilities, since particular effort is almost always made to operate and maintain full scale particulate control devices above the acid dew point. Daily start-up and shutdown compounded the problem of being representative of a full scale control device. It is not felt, however, that these conditions necessarily make the resulting operating and performance data less useful. After all, acid dew point excursions are primarily concerned with corrosion or system life. While there are other possible ramifications or effects, such as a potential alteration of dust cake characteristics, these were realized and attempts were made to evaluate them by duplicating one or two test conditions at higher temperatures and continuous operation. Table 4 presents the temperature profiles for the MSU comparison which duplicated the Amarillo conditions, and the added high temperature testing, hereafter designated HT. The HT temperature profiles are generally 100°F higher at all points.

Static pressures, shown in Table 5, were higher at Harrington Station due to greater negative plant duct pressures, thus requiring a return line to the process (the mobile unit at MSU emitted exhaust to the atmosphere). Static pressure drops through the baghouse were comparable at both sites.

8.0 OPERATING DATA

BAG CLEANING CHARACTERISTICS

Values for average filtration and effective residual bag pressure drop are presented in Tables 6 and 7 respectively. For the shake cleaning mode, average filtration time was significantly greater for the Western coal than for the Eastern coal. In the reverse air cleaning mode, problems were encountered at both sites. Filtration times were so short that an alternating reverse air-shake cleaning schedule was adopted for the G/G-RA case on Western coal and for both G/G-RA and T/G-RA on Eastern coal. The resulting average filtration times were the opposite of those for shake cleaning, i.e., they were higher for the Eastern coal than for the Western coal. However, the difference was not as significant. For all three cases alternating shake and reverse air cleaning produced similar results. The filtration time periods were much longer following shake cleaning, but grew successively shorter after a series of reverse air clean downs. This relationship will be discussed further when the bag ΔP vs. time curves are considered.

Table 3. TEMPERATUE PROFILES

	Amarillo		MSU(c)	
	°C	°F	°C	°F
T_1 Slipstream Takeoff at Plant Duct	180-200	(360-390)	170-180	(340-360)
T_2 Inlet Sampling Point	130-150	(270-300)	120-130	(250-270)
T_3 Baghouse Hopper	115-130	(240-270)	105-115	(220-240)
T_4 Top of Baghouse	90-105	(190-220)	90-100	(190-210)
T_5 Outlet Sampling Point	80-100	(180-210)	90-100	(190-210)
T_7 Reverse Air Duct	-	-	70-115	(160-240)

Table 4. TEMPERATURE PROFILES AT MSU

	Comparison Testing		High Temperature Testing	
	°C	°F	°C	°F
T_1	170-180	(340-360)	170-180	(340-360)
T_2	120-130	(250-270)	175-190	(350-370)
T_3	105-115	(220-240)	160-170	(320-340)
T_4	90-100	(190-210)	150-160	(300-320)
T_5	90-100	(190-210)	150-160	(300-320)
T_7	70-115	(160-240)	70-115	(160-240)

Table 5. STATIC PRESSURE PROFILES IN H_2O

	Amarillo	MSU
P_0 Plant Duct	10-17	2-4
P_1 Inlet Sampling Point	11-18	7-9
P_2 Outlet Sampling Point	16-22	8-13
P_3 Main Fan	17-23	11-16
ΔP Across Bags	4.0, max.	4.0, max.

Table 6. AVERAGE FILTRATION TIME

Bag Type	Western Coal (min)	Eastern Coal (min)
G/G-RA	20 (Rev. air) 30-60 (Shake)	20-70 (Rev. air) 80-110 (Shake)
T/G-RA	20-30	25-70 (Rev. air) 90-135 (Shake)
G/G-S	180	60-70
T/G-S	220	45-70
T/G-RA-HT	-	80-100 (Rev. air) 25-60 (Shake)
G/G-S-HT	-	90

Table 7. AVERAGE EFFECTIVE RESIDUAL BAG PRESSURE DROP IN H_2O

Bag Type	Western Coal	Eastern Coal
G/G-RA	3.1-3.5 (Rev. air) 2.4-3.1 (Shake)	2.3-2.7 (Rev. air) 1.3-1.5 (Shake)
T/G-RA	3.1-3.5	2.2-2.5 (Rev. air) 1.0-1.2 (Shake)
G/G-S	1.8	1.6
T/G-S	1.5	1.8*
T/G-RA-HT	-	2.3 (Rev. air) 1.2 (Shake)
G/G-S-HT	-	1.5

* High outlet loadings

Average effective residual bag pressure drop (Table 7) does not show such clear distinctions between sites. ΔP_{ER} values were comparable when shake cleaning was used at each site and somewhat lower for the Eastern coal when reverse air cleaning was used.

The results obtained in the reverse air cleaning mode are felt to be related to the mobile baghouse. It is apparent that insufficient cleaning energy is delivered to the bags. Without sufficient cleaning, the residual resistance climbs cycle by cycle almost limitlessly or at least above practical operating levels with respect to operating costs. In these studies, when cleaning is initiated at the same terminal ΔP, the increasing ΔP_{ER} precipitates shorter and shorter filtration times. This will be evident when we look at the ΔP vs. time curves.

Typical cleaning cycles (ΔP vs. time curves) for three cases are shown in Figures 3, 4 and 5. The data for the G/G-RA case (Figure 3) definitively shows the decreasing filtration time for successive reverse air cleaning cycles followed by much longer filtration periods and lower effective residual pressure drops after shake cleaning.

The data for G/G-S case (Figure 4), on the other hand, show fairly consistent values for both filtration time and ΔP_{ER}. Other factors which affect filtration time and residual resistance includes a significant change in inlet characteristics, as would be encountered either with a process upset or such a routine procedure as blowing soot or pulling bottom ash. The 35-minute filtration period at 10:30 corresponds to soot blowing.

Reentrainment of ash from the hopper exhibits the same effect, as is apparent in the data for the T/G-S case (Figure 5). Here the successively shorter filtration times are not the result of insufficient cleaning as was true of reverse air cleaning. In this second case, the effect is due to the filling of the hopper which causes increasing reentrainment of ash. When the hopper was emptied, the filtration times returned immediately to normal range.

CAKE RESISTANCE TESTS

The specific cake resistance coefficient, K_2, was determined for both bag types in the shake cleaning mode at each site. Results of these tests are shown in Table 8. If one ignores the 10.1 value for T/G-S case on Eastern coal (test results for this case are inexplicably high and were not considered in the data analysis), the lower value for the G/G-S case appears to correlate with differences in respective mass mean diameter. Dennis et al. have shown that K_2 values for two similar dusts with different size distributions vary inversely with the respective mass mean diameters.

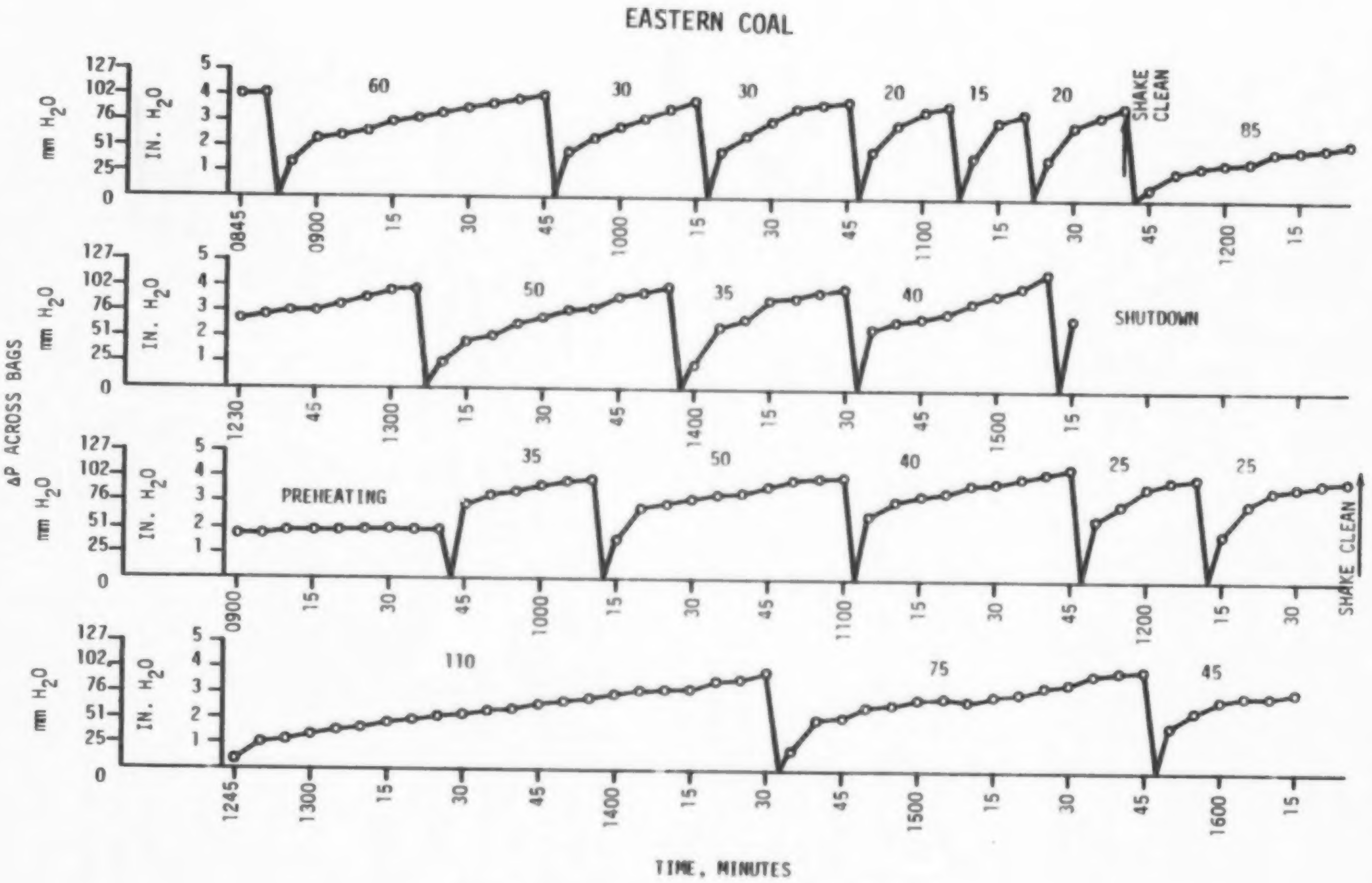

Figure 3. Graphite/glass bags - reverse air cleaning

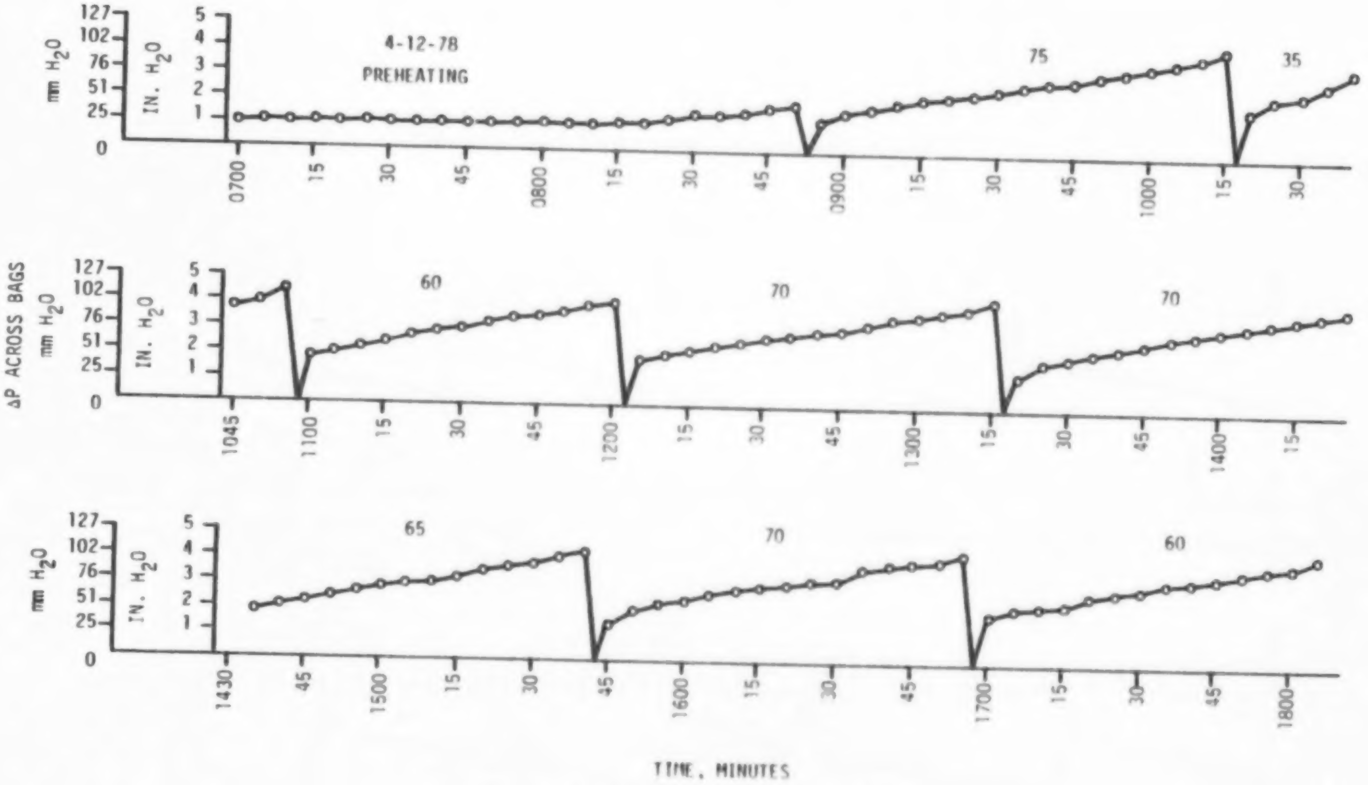

Figure 4. Graphite/glass bags - shake cleaning

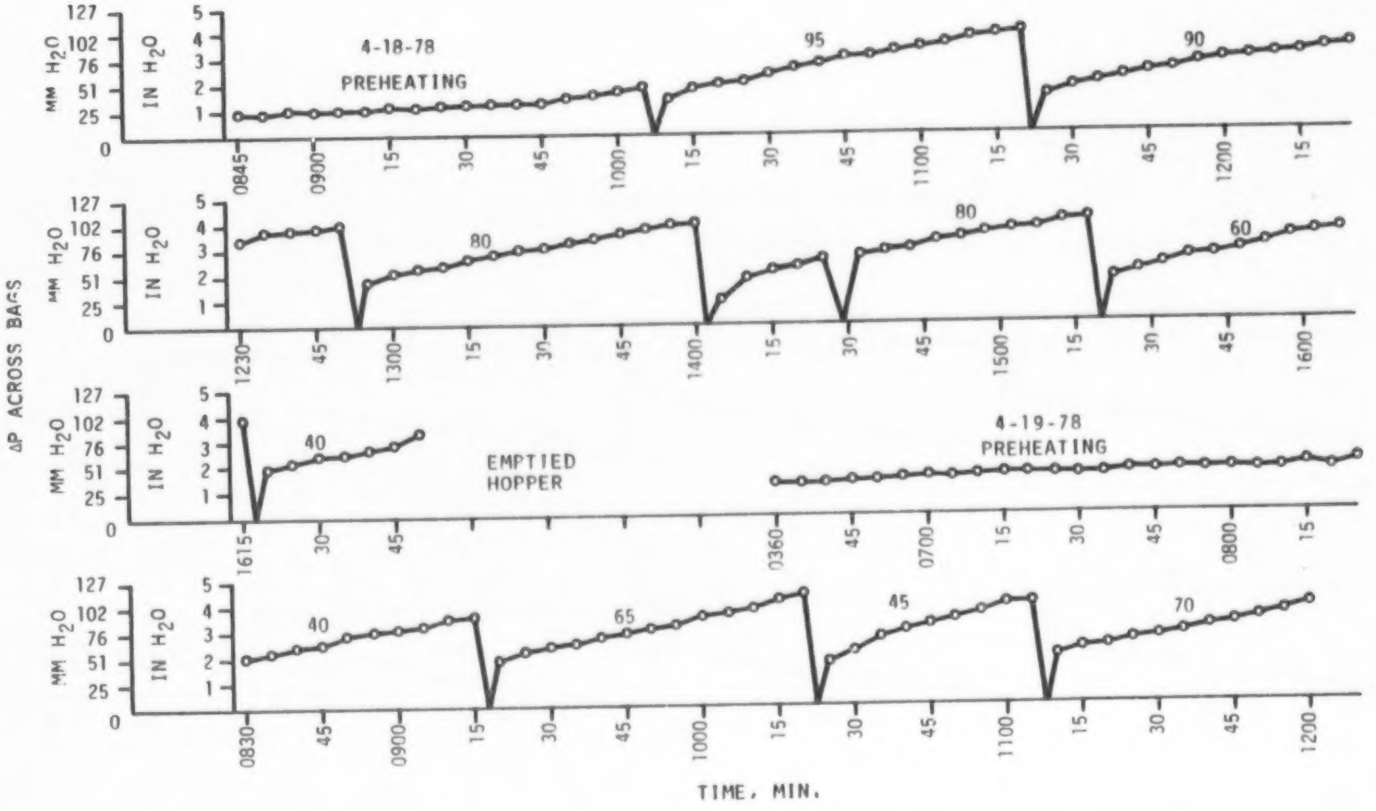

Figure 5. Teflon/glass bags - shake cleaning

9.0 PERFORMANCE MEASUREMENTS

TOTAL MASS CONCENTRATIONS

Table 9 presents the average inlet characteristics for both the MSU and Harrington Station sites. Although inlet grain loadings varied over a fairly wide range, there was no apparent correlation with either boiler load or outlet concentration. Therefore, the average inlet grain loadings were used to generate total mass efficiency and penetration levels for individual bag type/cleaning mode combinations. It should be noted that the average mass mean particle diameter for the Eastern Coal was 9.8 in and for the Western coal, only 3.5 Average outlet mass concentration, efficiency, and percent penetration are shown in Table 10. All values are generally comparable with the exception of two Eastern coal cases, teflon/glass-shake (T/G-S) cleaning, and graphite/glass-shake cleaning at higher temperatures (G/G-S-HT). No explanation of the high results for those cases is readily available. Samples in these cases were taken consecutively and corresponded to a period when ash content of the Eastern coal was much higher than average. Ash content for this short time period averaged 18 - 20 percent compared to an overall average of 14 percent. It is not felt that this alone, however, accounts for the higher outlet loadings since fabric filters are known to be relatively insensitive to variations in inlet loading concentrations. In order to prevent data from these two cases from masking trends which might otherwise be apparent, the results, as stated previously, were generally ignored during data analysis.

A ranking of bag type-cleaning mode by outlet concentration, presented in Table 11, reveals no significant differences between the two coal types. However, the order of G/G and T/G bags seems to be reversed when going from Western to Eastern coal. Performance based solely on outlet mass concentration in the T/G-Ra case did improve somewhat at higher temperatures. This was not repeated in the fractional efficiency of the smaller size cuts.

Table 12 shows the average outlet mass mean particle diameter for each case. The values on Eastern coal are consistently higher, and again the trend for Western coal is reversed when compared to the Eastern coal. The MMD's are higher for reverse air cleaning at the Western site, and lower at the Eastern site.

FRACTIONAL EFFICIENCY

Curves for fractional efficiency for the Western and Eastern coal are shown in Figures 6 and 7 respectively. All curves exhibit minima. The Western coal shake-cleaned bag minima were at larger particle sizes than those of the reverse-air-type bags. With both shake and reverse air clean, the minimum penetrations were at smaller sizes with the graphite/glass bag material. It is interesting to note that both reverse-air-cleaned bags exhibit similar curves, even though the graphite/glass bags were alternately shaken and reverse-air-cleaned during sampling.

Table 8. SPECIFIC CAKE RESISTANCE (K_2) TESTS

Bag Type	Western	Eastern
G/G-S	6.24*	4.3
T/G-S	7.83	10.1

* It is suspected that some cake fell from the bags before removal and final weighing. Thus, K_2 is believed to be a lower than actual value.

Table 9. AVERAGE INLET CHARACTERISTICS

	Western	Eastern
Gr/dscf	7.8	3.7
Mass median Particle diameter	3.5	9.6 (σ = 2.9)
SO_2, ppm	400	400-600
Moisture, %	8.5 - 10.5	6-8
O_2, %	1.5	8.8
CO_2, %	11.3	11.5
N_2, %	87.2	79.6
EA, %	6	30-40

Table 10. BAG PERFORMANCE, gr/dscf

Bag Type	Outlet Mass	Efficiency	Penetration, %
Western Coal			
G/G-RA	.0024	99.97	0.03
T/G-RA	.0078	99.90	0.10
G/G-S	.0039	99.96	0.04
T/G-S	.0087	99.83	0.17
Eastern Coal			
G/G-RA	.0083	99.78	0.22
T/G-RA	.0053	99.86	0.14
G/G-S	.0075	99.80	0.20
T/G-S	.0511	98.63	1.40
Eastern Coal - HT			
G/G-RA	-	-	-
T/G-RA	.0030	99.92	0.08
G/G-S	.0205	99.45	0.55
T/G-S	-	-	-

All mass units are gr/dscf

Table 11. BAG RANKING BY OUTLET CONCENTRATION, gr/dscf

Bag Type	Concentration
Western Coal	
G/G-RA/S	.0024
G/G-S	.0039
T/G-RA	.0078
T/G-S	.0087
Eastern Coal	
T/G-RA/S	.0053
G/G-S	.0075
G/G-RA/S	.0083
T/G-S	.0511
Eastern Coal - HT	
T/G-RA/S	.0030
G/G-S	.0205

All mass units are gr/dscf

Table 12. OUTLET MASS MEDIAN PARTICLE DIAMETER, μm

Bag Type-Cleaning Mode	Western	Eastern	Eastern - HT
T/G-RA	1.7	3.2	2.3
G/G-RA	1.5	2.8	-
T/G-S	1.2	3.8	-
G/G-S	0.8	3.6	4.4

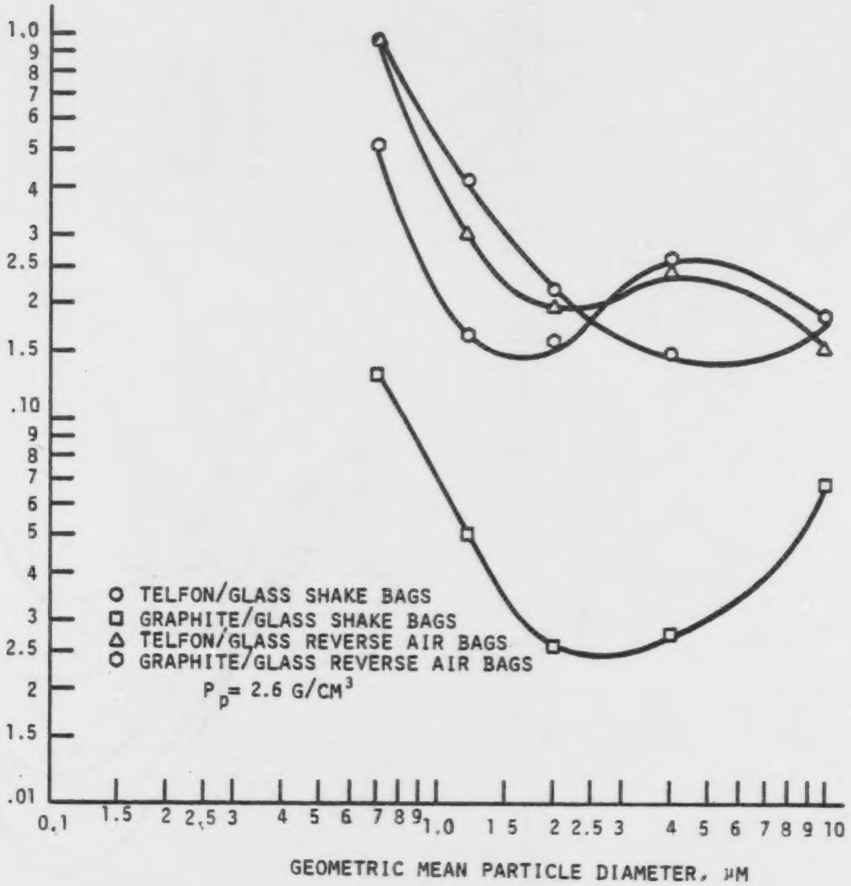

Figure 6. Average mass penetration vs. geometric mean particle diameter.

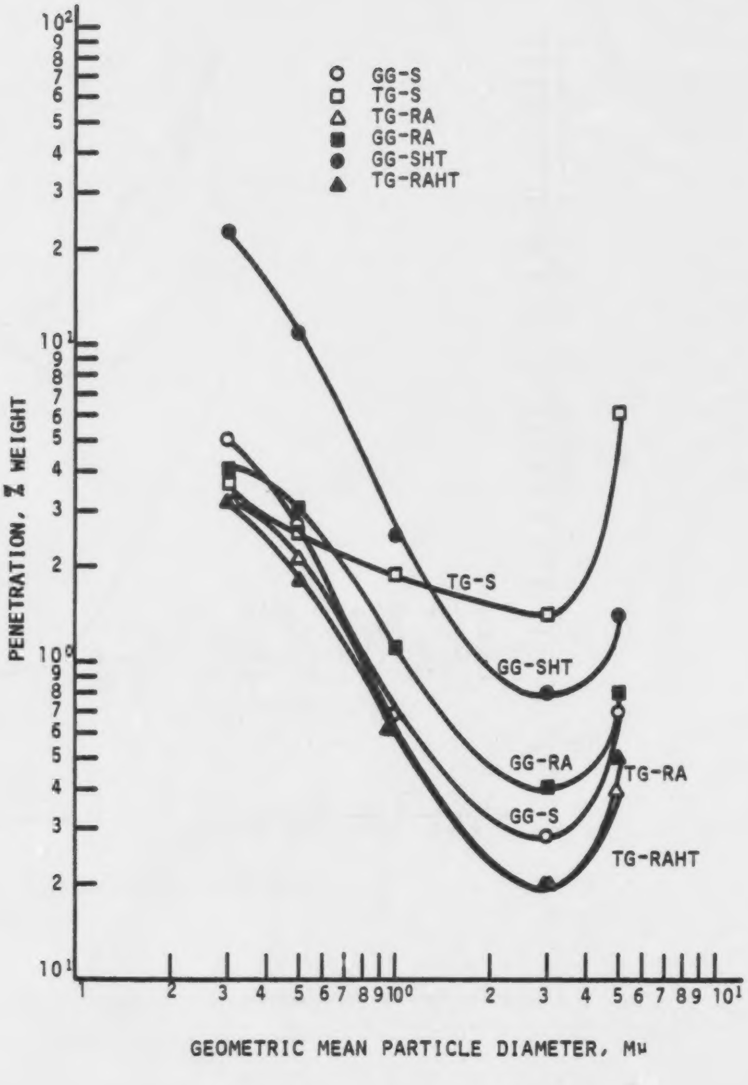

Figure 7. Geometric mean particle diameter, mμ.

The Eastern coal curves (Figure 7) all exhibit minima at 3 m with the Tg-RA and TG-RA-HT cases having the lowest penetration. This agrees with the ranking of bag type/cleaning mode based on outlet mass concentration. Again, it is believed that for particle sizes of 5μm and larger the data is biased by extractive sampling. Since the primary area of interest is that for fine particulates (or less than 3μm), the data for the smaller cuts is a realistic measure of performance. Generally, the curves for Western and Eastern coal fall in the same range with the exception of the G/G-S case on Western coal.

CONCLUSIONS

The data indicate an overall similarity with respect to performance and operating characteristics for the mobile baghouse as applied to an Eastern and a Western coal. Some differences or trends are indicated from which tentative conclusions can be drawn. Further comparative studies are certainly needed and would be more conclusive if fewer cases, i.e., bag type-cleaning modes, were considered.

- Overall performance of each bag-cleaning mode combination was comparable for the Eastern and Western coal.
- Graphite- and silicone-coated glass bags appeared to perform slightly better on the Western coal.
- Teflon-coated glass bags appeared to perform slightly better on the Eastern coal.
- Shake cleaning yielded longer filtration times and lower ΔP_{ER} for both coals.
- Mobile unit reverse air cleaning does not deliver adequate cleaning energy to the bags.
- Extractive impactor sampling is undesirable because high and erratic probe washes bias upper size cuts.

RECOMMENDATIONS

- Conduct comparative testing of a similar scope at a facility firing a pulverized Eastern coal with a higher sulfur/lower ash content.
- Conduct further pilot scale testing of pulverized Western coal for comparison with the Amarillo data.
- Establish operating conditions for future test programs to simulate real world conditions as closely

as possible, i.e., with realistic temperatures and continuous operation.

- Design and structure operating and data collection methodology to produce results suitable for predictive modeling and regression analysis.
- Reevaluate mobile baghouse reverse air cleaning mode to determine how representative it is of full scale systems.
- Increase ash hopper storage capacity and provide method of ash removal when unit is operating.
- Improve reverse air preheat operating procedure.

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2. Hall, R. R. Mobile Fabric Filter System-Design Report. U. S. Environmental Protection Agency (GCA/Technology Division [Bedford, Massachusetts], EPA Contract No. 68-02-1075). October 1974. p. 73.

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EVALUATION OF FELTED GLASS FILTER MEDIA UNDER SIMULATED PULSE JET OPERATING CONDITIONS

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INTRODUCTION

Pulse jet baghouses for industrial gas filtration have been successfully applied using a variety of needle felted organic fiber filter materials. However, in the filtration of coal burning industrial and utility boiler gases, organic fiber filters frequently do not meet application needs because of extreme temperature exposures or acid attack.

Reigel and Bundy[1] describe the use of woven fiberglass filter bags in pulse jet baghouses used on coal fired boilers to meet the demanding exposure conditions of these applications. The woven glass bags, while providing adequate degradation resistance, do not offer the filtration properties of felted materials. A felted glass filter material suitable for pulse jet baghouse application would provide the temperature and corrosion resistance of woven glass fabric with the prospect of affording better filtration properties than either woven glass or felts composed of organic fibers.

Huyck Research Center has developed an all glass felt called HUYGLAS filter fabric. This new filter material possesses unique performance characteristics owing to the very fine glass fibers which comprise the filter mat portion of the structure.

Several researchers have pointed out the effects of finer fibers in terms of increased filtration efficiency. Lamb et al[2] offer two possible explanations for this observed effect. The projected surface area of a constant mass of fibers is inversely proportional to the square root of the linear density. Fibers of lower linear density will therefore have more surface area per unit mass, and the probability of dust particle impaction is therefore increased. The second effect of lower linear density at constant mass is an increase in the number of fibers present and a consequent smaller average pore size between fibers. This effect may produce a somewhat higher initial flow resistance in filters made from fine fibers, but its effect upon ultimate filter-cake flow resistance is dependent upon other variables such as cake release and media-dust particle interactions.

In this paper, the filtration performance of HUYGLAS filter fabric under simulated pulse jet operating conditions is compared to three commercial filter fabrics used in high temperature pulse jet baghouse filtration.

The results indicate that the HUYGLAS filter fabric offers a valid alternative which may provide significant user benefits in selected pulse jet baghouse applications.

LABORATORY MASS EFFICIENCY TESTER

The Mass Efficiency Tester used in this study is similar to other laboratory devices used throughout the industry. The equipment is pictured diagramatically in Figure (1). Essentially, the unit consists of a mounting frame for accommodating pre-tensioned flat filter fabric samples having an active filtration area of 8 x 12 inches. Test dust is metered at the desired rate through a precision screw feeder onto a slowly rotating turntable. The dust advances half-way around the turntable to a point where it is vacuumed upward into the venturi of a compressed air driven ejector which breaks up dust particle agglomerations and redisperses the dust as it passes into the inlet duct. The dust-laden inlet air stream passes into the dust chamber where the test media is mounted. Air-to-cloth ratio is pre-set by means of a flow control regulator, with system vacuum provided by a high efficiency turbine. Dust-laden air filters through the test element before being exhausted to the atmosphere. The test fabric is cleaned periodically according to pre-set conditions to simulate pulse jet baghouse operation.

HUYGLAS™ is a trademark of Huyck Corporation.

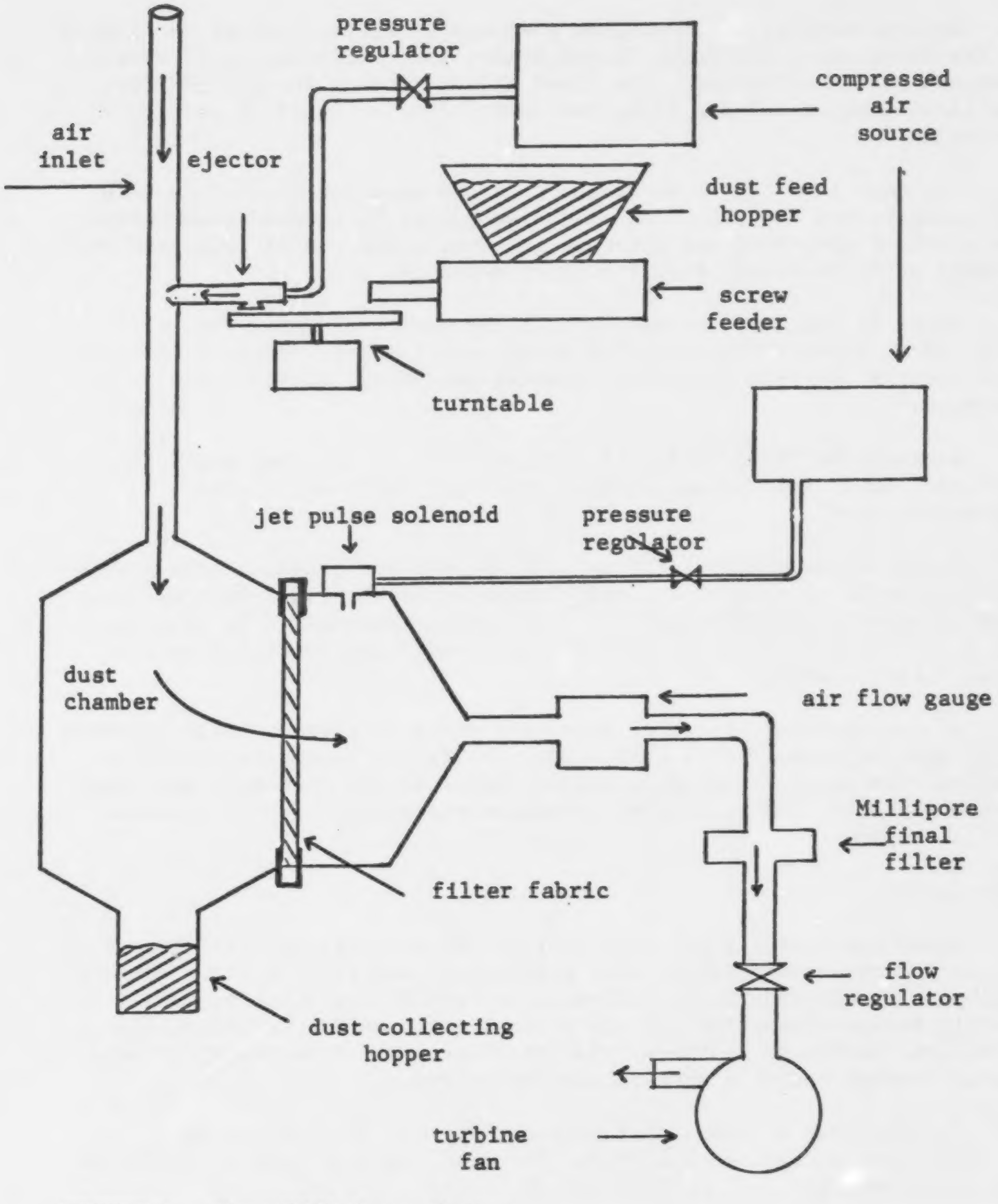
pressure regulator
compressed air source
air inlet
ejector
dust feed hopper
screw feeder
turntable
jet pulse solenoid
pressure regulator
dust chamber
air flow gauge
Millipore final filter
filter fabric
flow regulator
dust collecting hopper
turbine fan

FIGURE 1. Mass Efficiency Tester

TEST PROCEDURE

All testing was carried out under ambient conditions in the range of 65 to 75°F and 25 to 45% relative humidity.

Before start-up a pre-weighed glass paper filter element is mounted in the final stage millipore filter holder for determination of fabric dust collection efficiency. The final filter element is changed after the first hour of running time, and again after 20 hours of additional operation.

The dust feed hopper is filled to a constant level prior to each run using sieved fly ash. The entire apparatus is cleaned down before the start of each test and all dust fed during the run is collected and weighed after to verify dust feed rate accuracy.

Prior to the start of each trial, the mass efficiency tester is adjusted to provide the specified inlet dust loading, air-to-cloth ratio, dust ejector pressure and pulse cleaning frequency, duration and pressure.

Because the filter media is mounted close to the compressed air solenoid, lower than normal pulsing pressures are used in this laboratory test.

A continuous chart recording of flow rate and pressure drop across the test media is made. Mass efficiency during the first hour and average efficiency for the entire test period are determined by weighing the dust fraction passed through the test media and collected on the final filter element.

At the conclusion of each test, the media is given a final cleaning pulse and the dust feed is shut down. The filter fabric is carefully removed from the test stand, visually inspected for dust cake and clean side appearance, and weighed to determine the amount of dust retained on the sample.

TEST DUSTS

Three types of fly ash were included in the test series. Two of the test dusts were obtained from pulverized coal fired utility boilers which use electrostatic precipitators for fly ash collection. The Detroit Edison commercial fly ash product contains 80% by weight of particles finer than 325 mesh. The Michigan State University fly ash has an average particle size of 6 micro-meters.

Fly ash from an industrial spreader stoker fired boiler was obtained from a baghouse collector. Average particle size by weight is 7.5 micro-meters.

TABLE 1. FILTER MEDIA PROPERTIES

	NOMEX® FELT	TEFLON® FELT	WOVEN GLASS	HUYGLAS™ FILTER FABRIC
Fabric Weight, oz./sq. yd.	14.6	26.5	17	29
Thickness, inches	0.094	0.058	0.034	0.093
Permeability, cfm at 0.5" Water	40	27	30	40
Denier	2	6.7	-	0.25
Filter Mat Fiber Diameter, Micro-meters	14.3	21.2	-	3.8

NOMEX® and TEFLON® are registered trademarks of E. I. duPont & Co. Inc.

The stoker fired boiler fly ash can be described as having distinctly greater agglomeration tendencies than the two types of pulverized coal fly ash tested.

FILTER MATERIALS

Properties for the four types of filter fabric evaluated in this study are listed in Table 1.

STOKER FIRED FLY ASH

Table (2) lists the significant test results with fly ash from a spreader stoker fired industrial boiler. Test conditions were as follows:

Air-to-Cloth Ratio: 7.5:1

Inlet Dust Concentration: As indicated in Table

Dust Ejector Pressure: 40 psig

Cleaning Pulse Pressure: 40 psig

Cleaning Pulse Duration: 0.1 seconds

Time Between Cleaning Pulses: 90 seconds

Total Test Time: 20 to 21 hours

The Table shows pressure drop across the test media immediately before and after the cleaning pulse takes place. Pressure drop is shown after one hour and after twenty hours of on-stream operation.

Mass efficiency, or weight percentage of inlet dust retained by the media, is shown for the first hour of operation under the conditions indicated, and as an average for the full test period. Efficiencies under these laboratory conditions are higher than can be expected in the field. Several possible explanations may be suggested for this observed effect. Inlet dust may remain partially agglomerated after passing through the ejector; room temperature conditions may increase media efficiency; or the pulse cleaning pressure employed may preserve media pre-coat better than in the field. Efficiency results nevertheless provide useful insight into differences between media under controlled constant conditions.

For each inlet concentration, the corresponding value is shown for total dust delivered to the media between cleaning pulses.

Where samples were tested at higher than 0.5 grains/cubic foot inlet concentration, the fabrics were pre-conditioned by a 20 hour cycle at the 0.5 grain starting level.

Table 2. MASS EFFICIENCY TEST RESULTS USING FLY ASH FROM A

STOKER-FIRED INDUSTRIAL BOILER AT AN AIR-CLOTH RATIO OF 7.5:1

FILTER MEDIA	INLET GRAINS/ CU. FT.	TOTAL BETWEEN PULSES GRAINS/ SQ. FT.	PRESSURE DROP INCHES WATER, AFTER: 1ST HOUR BEFORE	1ST HOUR AFTER	20 HOURS BEFORE	20 HOURS AFTER	MASS EFFICIENCY % FIRST HR.	MASS EFFICIENCY % AVERAGE	DUST ON FILTER, GRAMS
Woven Glass	0.38	4.3	1.4	0.4	4.4	1.4	98.67	99.80	9
Woven Glass	0.5	5.6	1.5	0.5	12.0	6.1	98.66	99.85	24
Woven Glass2)	1.84	20.7	19.1	14.0	1)	1)	99.95	n.a.	26.5
Nomex Felt	0.5	5.6	1.5	0.5	30.0	22.0	99.50	99.96	67
Nomex Felt	0.5	5.6	1.2	0.5	32	23	99.51	99.96	n.a.
Teflon Felt	0.5	5.6	1.1	0.4	16.6	8.7	99.68	99.98	40
Teflon Felt	0.5	5.6	1.1	0.4	18.9	11.2	99.72	99.97	61
HUYGLAS™ Felt	0.5	5.6	2.0	0.9	5.6	2.7	99.80	99.98	7
HUYGLAS™ Felt	0.5	5.6	1.9	0.8	5.8	2.5	99.76	99.92	10
HUYGLAS™ Felt2)	1.84	20.7	6.8	2.6	8.4	3.5	99.98	99.99	9
HUYGLAS™ Felt2)	2.75	30.9	8.0	2.6	11.4	4.6	99.98	99.99	11

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1) Test discontinued because of excessive pressure drop.
2) Fabric pre-conditioned at 0.5 grains/cubic foot inlet concentration for 20-21 hours.

n.a. Data not available.

Weight of dust retained on the filter media at the conclusion of testing is also indicated in the Table.

Mass efficiency for the woven glass fabric is lower than for the three felted media included in the series. First hour efficiencies for the woven glass are less than 99%, except in the case of the 1.84 grains/cu. ft. inlet sample which has been pre-conditioned, as mentioned earlier. Average efficiency for the three felted media are quite comparable, and in all cases exceed 99.9%.

Referring to the woven glass tests, at 0.38 and 0.5 grains/cu. ft. inlet concentrations, it can be seen that small differences in feed rate can cause large changes in filter resistance and retained dust cake. It appears that the ability of this woven glass fabric to maintain low flow resistance and clean-down after each pulse lies within the narrow tolerance band which is spanned by the conditions in this test series.

Figure (2) shows pressure drop before pulse cleaning versus time for all four fabrics at the 0.5 grains/cu.ft. inlet concentration. The HUYGLAS felted fabric shows a rapid initial pressure build-up, followed by a relatively slow increase in flow resistance over the last ten hours of testing. The woven glass fabric stabilized to a lesser extent, and at a higher final flow resistance level.

The Nomex felt did not achieve a stable operating mode under the 0.5 grains/cu. ft. inlet concentration. Pressure drop steadily built up over the duration of the test. The Nomex felt was covered with a firm dust cake about 1/8" in thickness, except for a small central area. Apparently, this area, covered with a thin dust coating, accounted for most of the flow through the Nomex felt toward the end of the test period.

Teflon felt also tended to operate at excessive pressures, building and maintaining a substantial non-homogeneous cake during the test run. The heavier retained dust cakes are all associated with higher operating pressure drops both before and after pulse cleaning.

Several factors may have contributed to the high pressure drop observed for Nomex and Teflon felts. The pulse cleaning pressure used in these experiments may have been marginal for these materials but entirely adequate for the smoother woven glass and HUYGLAS filter fabric. The tendency for the organic felts to stretch during testing may have resulted in some loss of pulse cleaning intensity due to increased fabric motion. Another important aspect was that at the conclusion of testing, both types of organic fiber felts had numerous fiber out-croppings interspersed within the dust cake. These surface fibers may have been raised through repeated pulsing. Their presence could increase cake retention and consequently increase media flow resistance.

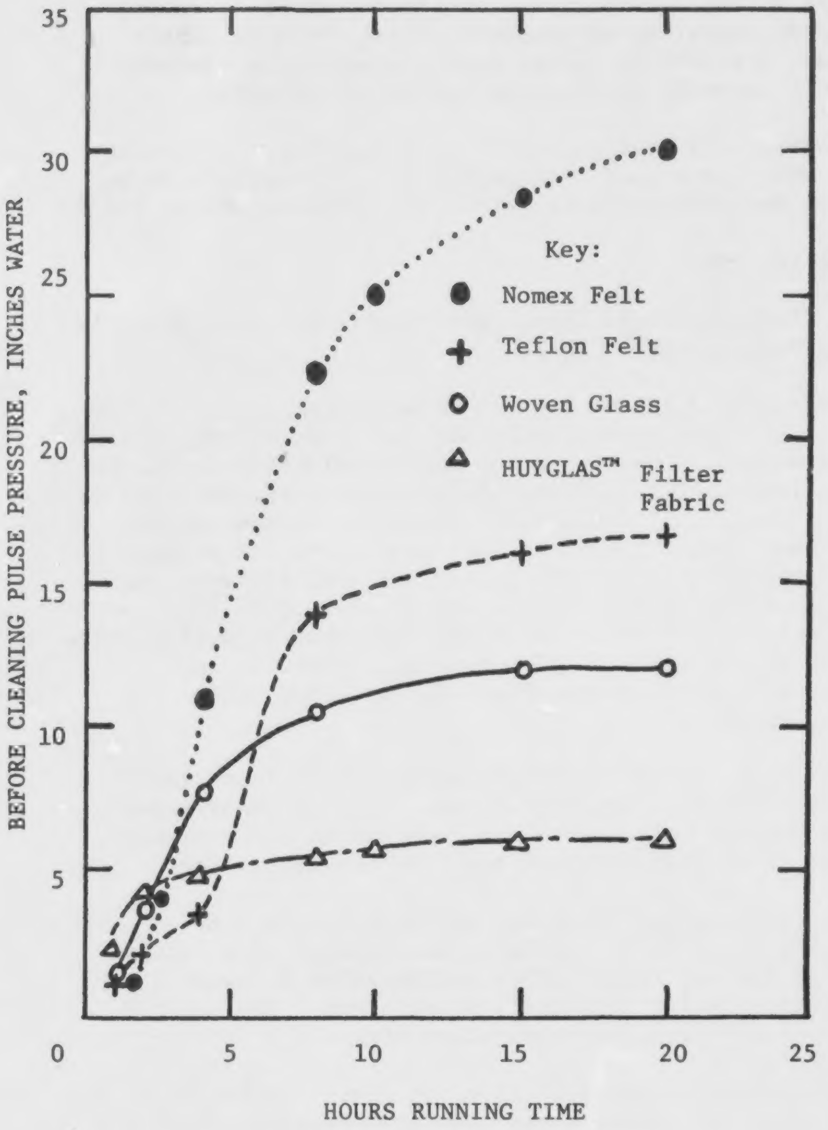

Figure 2. Pressure Drop Versus Time for 0.5 Grains/Cu. Ft. Inlet Loading with Stoker Fly Ash

The HUYGLAS filter fabric showed distinctly lower operating pressure drop under equal inlet concentrations. Even at higher inlet dust loads, the HUYGLAS filter fabric showed less tendency to retain dust or increase in flow resistance, by blinding.

The mass efficiency test is useful as a laboratory screening tool. Fabrics which show good performance by this test should be subjected to further evaluation in pulse jet baghouses in the field.

PULVERIZED COAL FLY ASH

Table (3) lists the significant test results obtained with fly ash from two pulverized coal boilers.

The use of pulverized coal fly ash necessitated substantially different dust feed rates between cleaning pulses to obtain similar fabric flow resistance as were observed with HUYGLAS filter fabric using a stoker fired boiler fly ash. To generate pressure drops of roughly the same magnitude, total dust delivered between pulses had to be increased from 4 grains/sq. ft. level used for stoker fly ash to 120 grains/ sq. ft. with pulverized coal fly ash, and even with this increase, media flow resistance was still lower for the pulverized coal series. It is believed that this difference is due primarily to the greater agglomerating tendencies and structural integrity of the stoker-fired fly ash, but other explanations may exist.

Results are shown for air to cloth ratios of 10:1 and 15:1 using fly ash obtained from Detroit Edison. In this comparison total dust feed between pulses was kept constant at 120 grains/sq. ft. by adjusting inlet concentration and time between pulses.

The data using Michigan State fly ash were obtained at an air-to-cloth ratio of 12.75:1. Included are results of a HUYGLAS filter fabric bag removed from a pilot plenum pulse baghouse installed at Michigan State University power plant. The bag had been in continuous operation for about five weeks.

At an air-to-cloth ratio of 10:1, woven glass, Teflon felt, and HUYGLAS filter fabric operated at efficiencies exceeding 99%. The HUYGLAS filter fabric exhibited the lowest pressure drop.

At an air-to-cloth ratio of 15:1 tests on woven glass had to be terminated after only 2 1/2 hours on stream because of final filter element plugging. This fabric showed a decrease in filtration efficiency with time possibly due to operation at high flow rates for this media.

TABLE 3. MASS EFFICIENCY TEST RESULTS USING FLY ASH FROM PULVERIZED COAL BOILERS

FILTER MEDIA	PRESSURE DROP " WATER, AFTER: 1ST HOUR BEFORE	1ST HOUR AFTER	20 HOURS BEFORE	20 HOURS AFTER	MASS EFFICIENCY % 1ST HOUR	MASS EFFICIENCY % AVERAGE	DUST ON FILTER, GRAMS
Detroit Edison:	Air: Cloth Ratio 10:1, Inlet Dust 3 Grains/Cu. Ft. 4 Minutes Between Pulses						
Woven Glass	1.2	0.4	2.7	1.2	99.76	99.96	15.1
Teflon Felt	0.5	0.15	1.7	0.9	99.97	99.99	11.4
HUYGLAS Filter Fabric	0.3	0.17	1.1	0.7	99.96	99.99	9.9
Detroit Edison:	Air: Cloth Ratio 15:1, Inlet Dust 4 Grains/Cu. Ft. 2 Minutes Between Pulses						
Woven Glass	1.7	1.0	9.7[1]	6[1]	99.56	98.58[1]	36.2
HUYGLAS Filter Fabric	1.0	0.6	3.8	2.4	99.76	99.99	17.1
Michigan State:	Air: Cloth Ratio 12.75:1, Inlet Dust 2 Grains/Cu. Ft. 1 Minute Between Pulses						
Teflon Felt	0.65	0.3	1.7	0.9	99.94	99.99	n.a.
HUYGLAS Felt	0.7	0.5	1.2	0.6	99.95	99.99	n.a.
HUYGLAS Filter Fabric After[2] Field Exposure	1.8	0.9	2.6	1.4	99.96	99.99	n.a.

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[1] After 2 1/2 hours.

[2] Sample taken from a bag which had operated in a pulverized coal boiler baghouse for approximately five weeks.

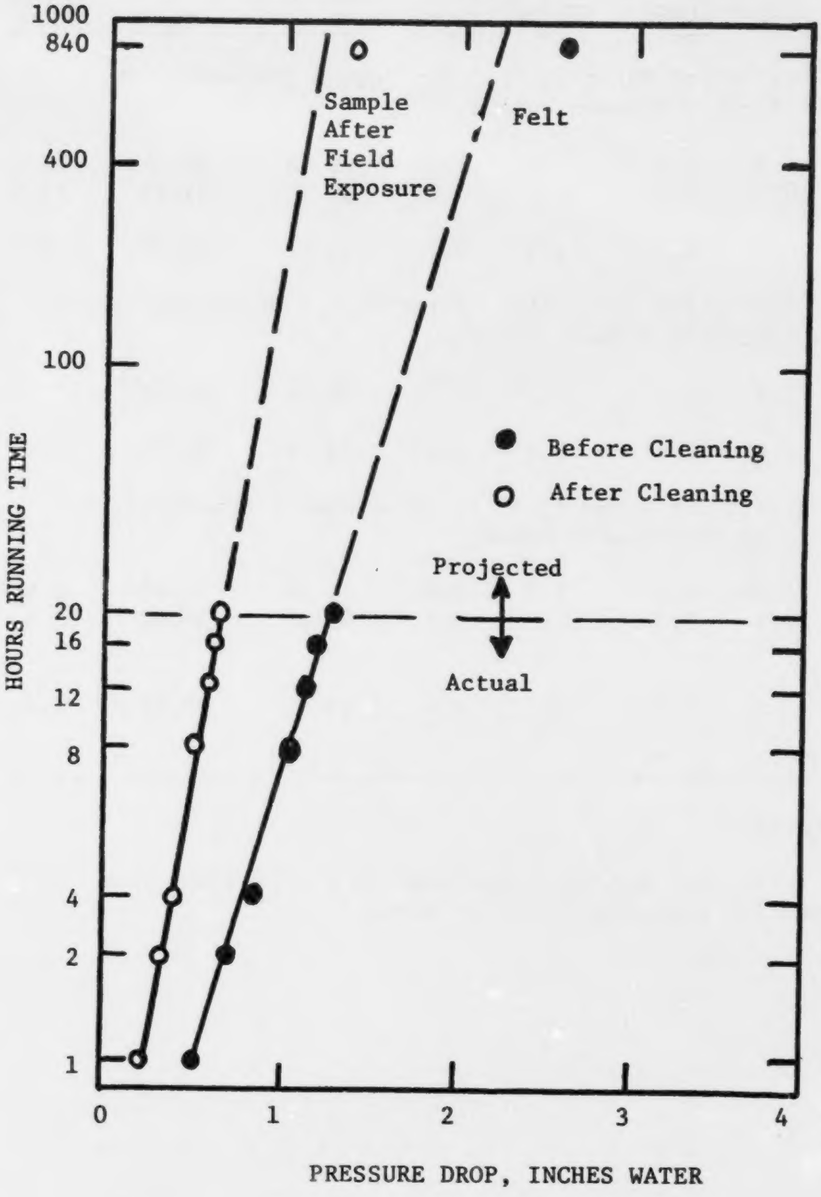

Figure 3. Mass Efficiency Flow Resistance Versus Log Time for New and HUYGLAS Filter Fabric and HUYGLAS Filter Fabric After 5 Weeks Field Exposure.

Results obtained on Teflon felt and HUYGLAS filter fabric with the Michigan State pulverized fly ash are reasonably consistent with the Detroit Edison dust findings at the 10:1 air-to-cloth ratio. After 20 hours on stream, differences in dust source, air-to-cloth ratio, and quantity fed between pulses cancel out to give an almost identical pressure drop comparison.

Comparing the HUYGLAS filter fabric sample after field exposure to the new sample, an expected higher flow resistance can be observed. If the laboratory flow resistance before and after pulse cleaning for the new media sample are plotted on a linear scale against a log scale for time, an extrapolation may be generated for media resistance after five weeks operation with this dust. Figure (3) shows this graph, with the used HUYGLAS filter fabric final pressure drop points plotted at the five week (840 hour) mark.

Although the points do not precisely fall in line with the extrapolation, a reasonable first approximately is obtained.

Although information from laboratory tests cannot correlate exactly with actual baghouse operating experience, such tests serve to provide a relative ranking of various filter media.

This work indicates that HUYGLAS filter fabric operates at significantly lower pressure drops compared to Nomex, Teflon and woven glass, using fly ash from stoker fired boilers. On fly ash from pulverized coal-fired boilers, the HUYGLAS filter fabric exhibits lower pressure drop and higher operating efficiency at high air-to-cloth ratios than woven glass.

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Journal Articles

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2) Lamb, G. E., Constanza, P. and Miller, B. "Influences of Fiber Geometry on the Performance of Nonwoven Air Filters" Textile Research Journal 45:452, June 1975.

ACKNOWLEDGMENT

The author wishes to express his appreciation to Dr. Raymond Z. Naar and Mr. Joseph B. Rabatoy for their many helpful contributions throughout this study.

INFLUENCE OF FIBER DIAMETER ON PRESSURE DROP AND FILTRATION EFFICIENCY OF GLASS FIBER MATS

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ABSTRACT

Glass Fiber Mats are used for filtration of particulates emitted by industrial processes. They are especially useful for filtration of submicron liquid smokes. The relationship between the diameter of the fibers composing the mats and the smoke penetration at varying air velocities is described. The effect of fiber diameter on pressure drop at varying air velocities is shown. Graphs are presented showing pressure drop effect on smoke penetration for the three fiber diameters studied.

INTRODUCTION

The work described in this paper is an extension of that reported in a paper published July, 1970[1]. The previous paper described filtration of smoke by mats composed of one micrometer fibers and by mats composed of larger fibers but impregnated with asbestos fiber.

This paper discusses filtration of the oil-smoke effluent from a roofing material asphalt saturator in a Johns-Manville plant, using mats that are made up of glass

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fibers with 1.4, 4.4, and 7.8 micrometers average diameter respectively. These mats are made of glass fibers held together with appropriate phenol-formaldehyde resins but not impregnated with any asbestos fibers or other materials.

The filtration method described in both the previous paper and in this one has proven to be extremely useful. Well over 120 full scale installations have been made to filter various industrial effluents.

TEST METHODS AND MATERIALS

Filter Test Assembly

A sheet metal duct, 5 inches in diameter, was inserted into one of the exhaust ducts carrying the oily effluents from the roofing plant saturator. The duct was installed so that it pointed upstream into the air flow and was located in the center of the duct. The subject duct was attached to a filter holder which held different diameter filter samples, depending on the material being tested. A duct after the filter holder was connected to a fan which drew the smoke sample from the duct through the filter and through the duct work.

Flow and Pressure Drop Measurement

The duct after the filter holder was long enough so that pitot tube readings could be taken through a hole drilled in the duct wall. Manometer connections were provided above and below the glass mat location in the filter holder. Manometers connected to these openings measured pressure drop across the filter under the various flow conditions.

Filter Efficiency

A Sinclair-Phoenix photometer was used for efficiency determinations. The photometer reads forward light scattering intensity caused by particles in the air stream drawn through the instrument. The instrument is adjusted to read 100% when the unfiltered gases ahead of the filter pass through the photometer chamber. Samples of the filtered gas drawn through the photometer give readings in percent of the intensity caused by the unfiltered gas. The reading gives the percent penetration of the smoke through the filter. One hundred minus the photometer reading gives efficiency.

Materials Tested

Table 1 shows the designation and some of the physical properties of the filters tested. As can be seen these mats are composed of fibers of three different diameters - 1.4, 4.4, and 7.8 micrometers.

Table 1. PHYSICAL PROPERTIES

Filter type	Fiber diameter (micrometers)	Mat thickness (inches)	Density (Lbs./cu.ft.)	*Pack factor
Fine	1.4	0.5	0.6	0.3
Medium	4.4	1.5	0.4	0.6
Coarse	7.8	1.0	0.6	0.6

(All materials are composed of flame attenuated fibre)

* Pack factor is a number obtained by multiplying the mat thickness in inches by the density in lbs./cu.ft.

RESULTS

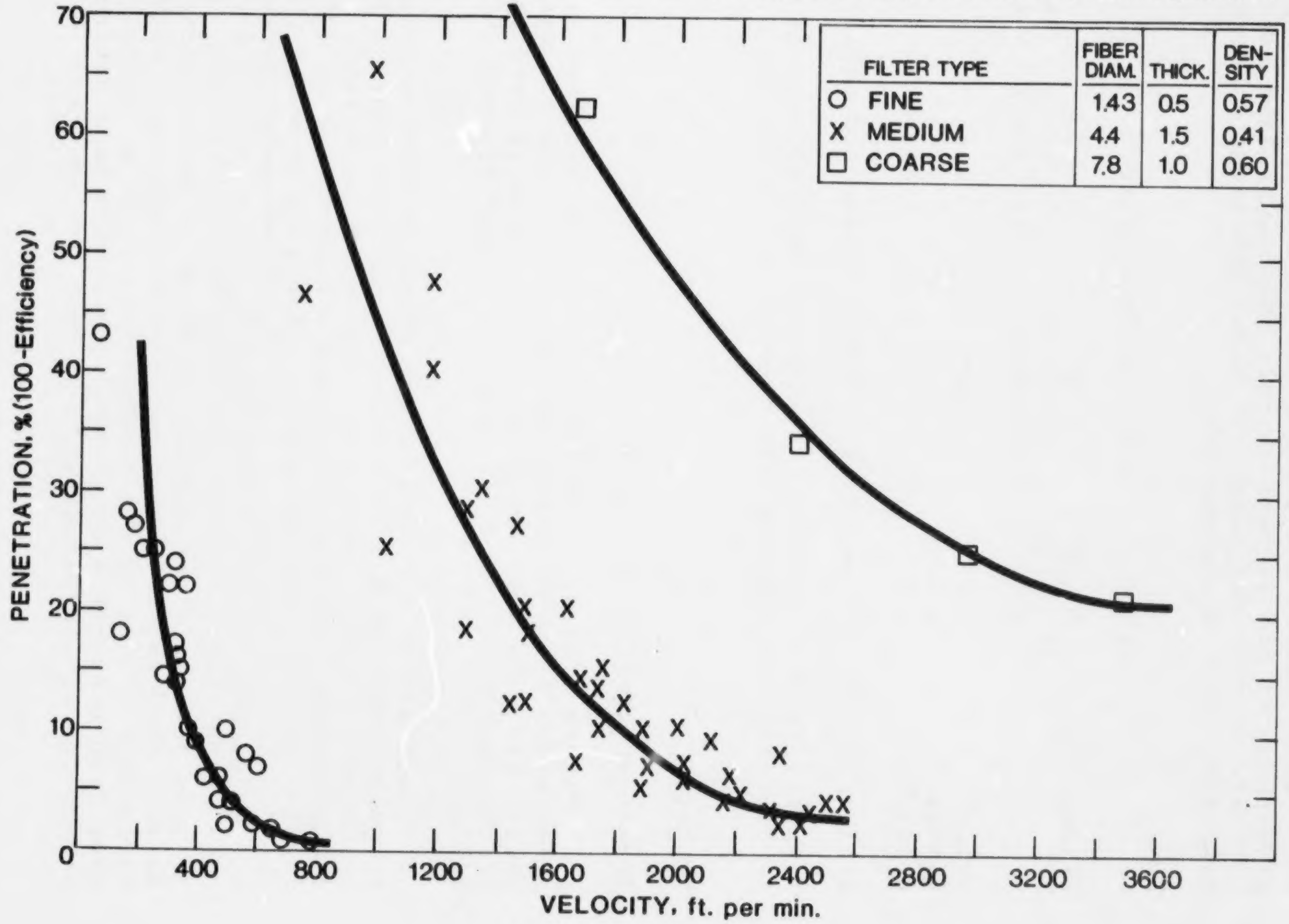
Smoke Penetration versus Velocity

Figure 2 shows the effect of fiber diameter on smoke penetration plotted versus the velocity of air through the filter mat. Each of the three curves shows reduced smoke penetration with increased velocity of air through the filter.

Each mat of different fiber diameter shows a reduction of penetration in a different range of velocities in feet per minute through the filter material. For example, the 1.4 micrometer fiber material has a penetration of 30% at a little over 200 feet per minute. Penetration drops to less than 1% at 800 feet per minute. The fiber mats composed of 4.4 micrometer fibers show a penetration of 30% at a little over 1,200 feet per minute velocity through the mat, while it goes down to a penetration of about 3% at velocities between 2400 and 2500 feet per minute. Mats made of 7.8 micrometer fibers have a penetration of 30% at velocities over 2600 feet per minute and approach 20% penetration at velocities of approximately 3600 feet per minute.

Figure 2

EFFECT OF FIBER DIAMETER ON SMOKE PENETRATION VS. AIR VELOCITY



The data indicates that the finer fibers make up filters that produce lower penetrations at a minimum. Although the data has not been extended far enough to be certain, it appears that the penetration of smoke thru 1.4 micrometer material may become asymptotic at penetrations below 1% and at velocities over 800 feet per minute. Similarly the curve for 4.4 micrometer fibers appears to become asymptotic at penetrations of approximately 3% at velocities above 2400 and 2500 feet per minute.

Pressure Drop versus Air Velocity

Figure 3 has three different curves showing the relationship of fiber diameter to the pressure drop caused by air flow through the filters at various air velocities. None of the curves is a straight line. The relationship between pressure drop and velocity for each fiber mat is probably given by a second order equation.

The finer the fiber diameter of the fibers making up the filter mats, the higher the pressure drop of air flow through the mat at the same velocity. Conversely, at the same pressure drop across the filter, the smaller the fiber diameter the lower the velocity required to produce that pressure drop. At 800 feet per minute velocity through the filter, the mat made up of 1.4 micrometer fibers gives a pressure drop of 24 inches of water. At that same velocity the 4.4 micrometer material produces a pressure drop of about 4 inches of water. The 7.8 micrometer material at a velocity of 800 feet per minute through the material, has a pressure drop of about 1 inch of water.

The 1.4, 4.4, and 7.8 micrometer fiber materials show a pressure drop of 10 inches of water at velocities of 400 feet per minute, 1400 feet per minute, and 2600 feet per minute respectively.

Pressure Drop versus Penetration

Figure 4 depicts the effect of fiber diameter on curves of pressure drop versus penetration. The interesting result of these curves shows that finer fibers produce filters giving the same efficiency as filters composed of larger diameter fibers, but at lower pressure drop across the material. For example, the filter made up of 1.4 micrometer fibers shows a penetration of 25% at about 4 1/2 inches of pressure drop. The 4.4 micrometer material shows the same penetration at a pressure drop of about 8 inches of water, twice as much. The 7.8 micrometer filter has a pressure drop of about 12 inches of water at a penetration of 25%.

Figure 3

EFFECT OF FIBER DIAMETER ON PRESSURE DROP VS. AIR VELOCITY

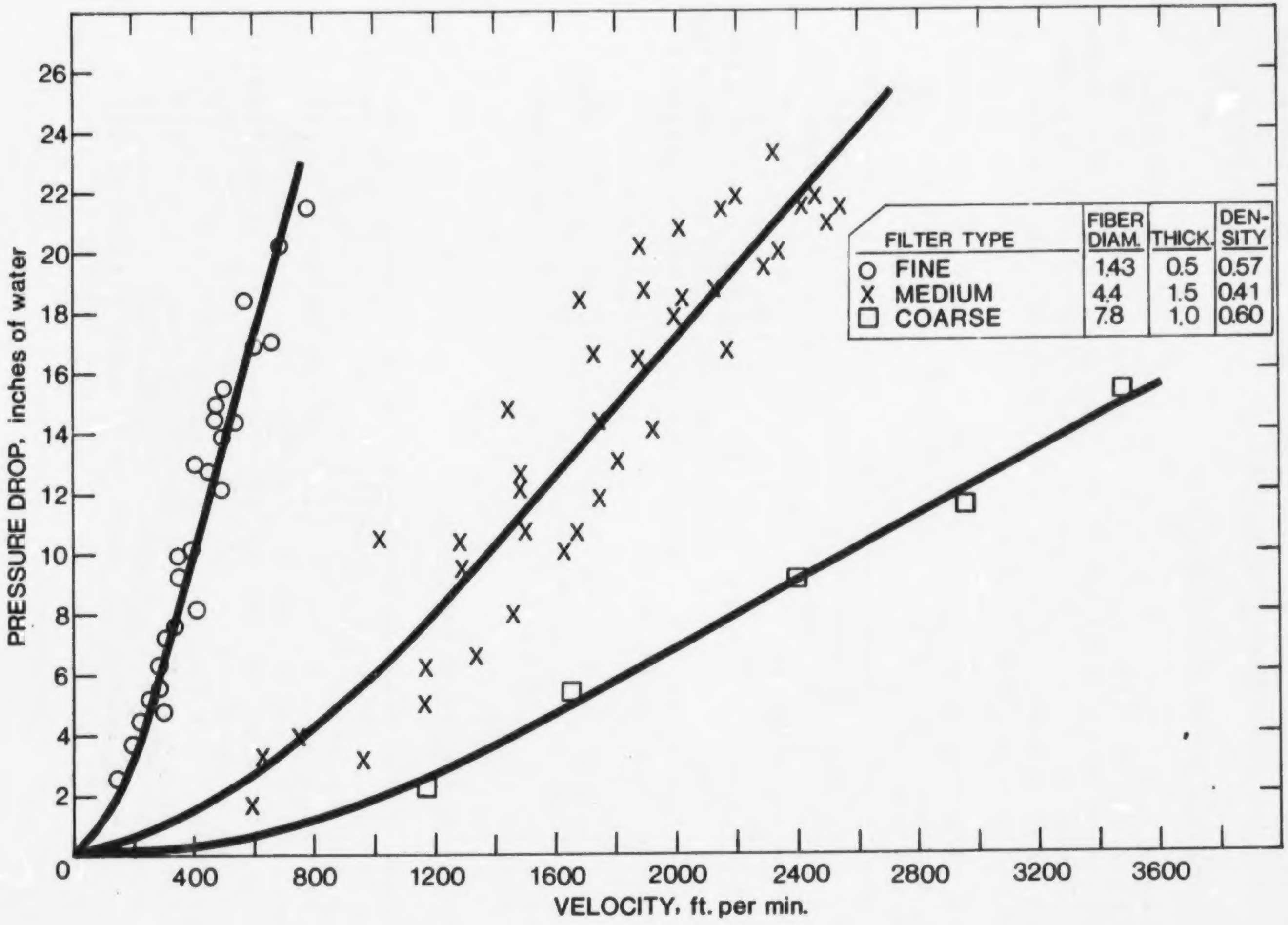
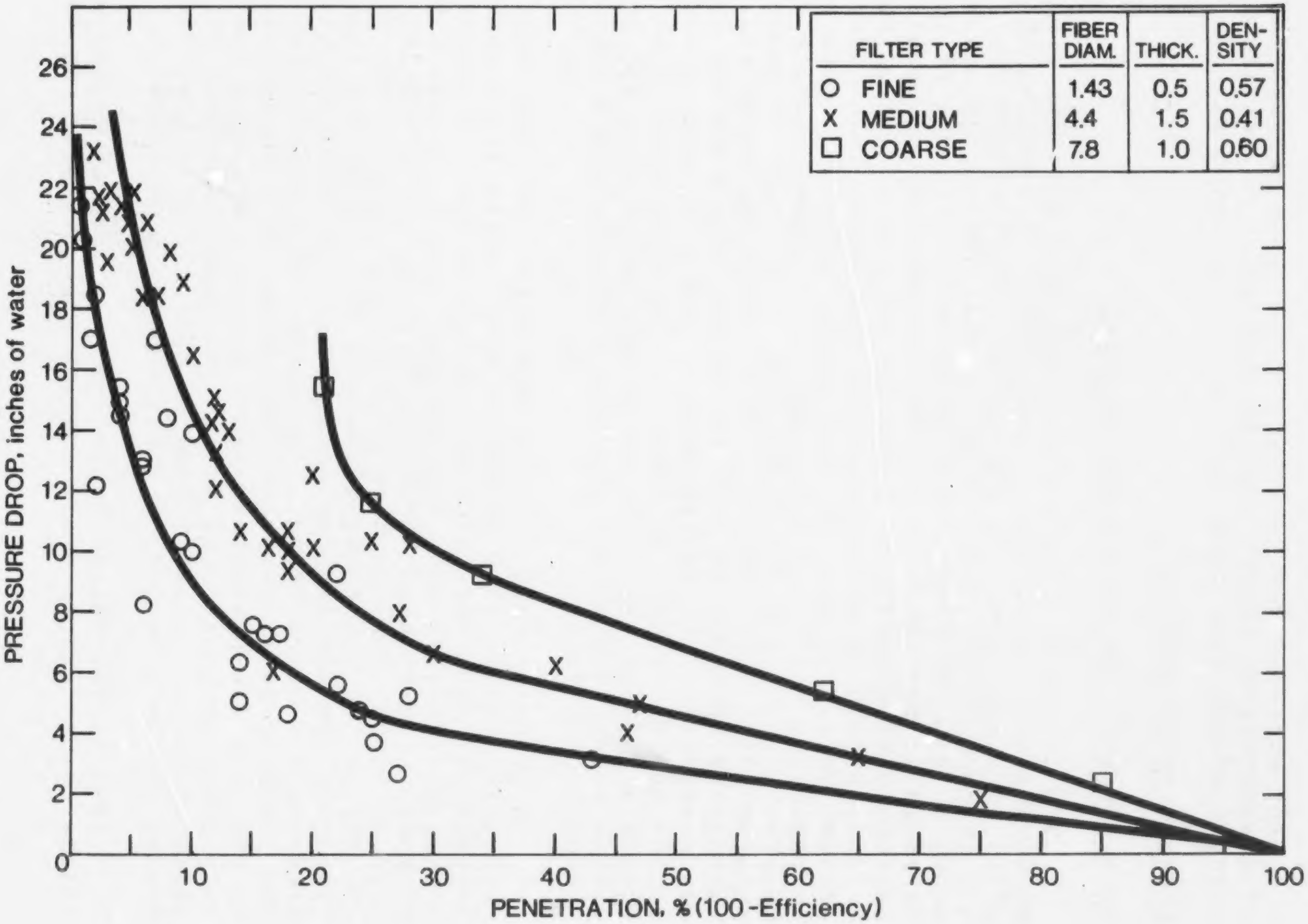


Figure 4

EFFECT OF FIBER DIAMETER ON PRESSURE DROP VS. PENETRATION



Conversely, at 14 inches of water pressure drop the mats made up of 1.4 micrometer fibers have a penetration of 5%. At that same pressure drop the 4.4 micrometer fiber filter gives a penetration of 11 to 12%, but mats made of 7.8 micrometer fibers produce a penetration of 22%.

The curves shown in figure 4 are drawn through the 100% penetration point. In the discussion of results it is pointed it out that this fact may not be correct.

DISCUSSION OF RESULTS

Smoke Penetration versus Air Velocity

The curves in figure 2 indicate that inertial effects predominate in the filtration mechanism of removing the small particles from the air stream. That effect explains why in each of the three cases studied increasing velocity shows decreasing penetration of smoke through the filter. Although it was not part of the present study, it would be extremely interesting to carefully explore the relationship of penetration versus velocity at velocities below those studied in this work. It is probable that the curves would go through a maximum penetration and at some velocity the penetration would start decreasing. This fact is especially true of 1.4 micrometer mats. Other work has shown that at velocities of under 20 feet per minute this material is an extremely efficient filter against small diameter particles. If the curves behaved in the way it's postulated, then of course diffusion processes would have taken over and that effect would predominate as penetration decreases with decreasing velocity.

As shown in table 1, the Pack Factor for the fine fiber filter is half of what it is for both medium and coarse materials. (The Pack Factor is a number that is proportional to the quantity of material per unit area.) It would be reasonable to assume that lower Pack Factor materials produce higher penetrations at the same air velocity thru the filter and would require higher air velocities thru the filter to produce reduced penetration. In spite of that difference in Pack Factor, the curves of figure 2 show that the 1.4 micrometer material filters at the same efficiency as the 4.4 micrometer material, but at a velocity that is only 1/6th as great. It is obvious that the effect of fiber diameter is considerably greater than the effect of Pack Factor on the behavior of these materials as filters.

This latter result introduces the idea of trying still thinner materials of still smaller pack factors. In fact, it would be interesting to try very thin layers of 1.4 micrometer material laid down on substrates made of much larger diameter fibers, to give strength and support.

The smoke emitted by a roofing plant saturator is caused by the vaporization of relatively low boiling hydrocarbons from the mass of molten asphalt and the subsequent cooling and condensation of those hydrocarbons. Such uncontrolled formation of particulates could be expected to produce a range of particle sizes. However, the blue color of the smoke, observed under certain conditions, indicates that a considerable proportion of the smoke is sub-micron.

The asymptotic values at the low penetration ends of the curves may be caused by penetrations of the smaller size component of the particulates. The cut off point of particle size filtered may be different for the mats of the three different fiber diameters. It is possible that the cut off point for small particle filtration increases in particle size as the fiber diameter of the fibers composing the mats increases in size.

Pressure Drop versus Air Velocity

The curves of pressure drop versus air velocity shown in figure 3 are curves because the air flow through the mats is in the turbulent flow region instead of the laminar flow region. It would be interesting to explore the relationship between pressure drop and velocity more fully. If it proves to be the case that the pressure drop varies as the square of the velocity then that would almost certainly prove that the data is completely in the turbulent flow range.

The mats compress with increasing air velocity and pressure. It is possible that the effect of compression has some effect on the pressure drop curve varying from a straight line.

As discussed above, the Pack Factor of the 1.4 micrometer material is only half as great as that of the 4.4 micrometer material and of the 7.8 micrometer material. All other things being equal, it would be expected that higher Pack Factor materials would produce higher pressure drops. In spite of that, the pressure drop at, for example, 800 feet per minute, is 24 inches for the 1.4 micrometer material and only 4 inches for the 4.4 micrometer material, a ratio of 6 to 1. It is quite obvious that the fiber diameter has a much more profound effect on pressure drop through the material than does the Pack Factor.

Pressure Drop versus Penetration

As discussed above, the 3 curves of figure 4 are shown to go through 100% penetration at 0 pressure drop. The relationship between penetration and pressure drop should be more fully explored at very low pressure drops. As discussed before, it is quite possible that at low pressure drops, which is the same as saying at low velocities, that diffusion processes start increasing in importance and the penetration starts falling after some maximum penetration has been attained. It is also possible that the diffusion effects can cause the penetration to drop to extremely low values at very low values of pressure drop.

Figure 4 shows the interesting result that filters made up of smaller diameter fibers are more efficient as regards power consumption. At similar penetration, the 1.4 micrometer material requires less pressure to pass air through the filter than for the larger diameter fiber filters. Although this fact appears to indicate that small diameter fiber filters are more desirable, that is not necessarily the case. Since the 1.4 micrometer material must be run at about 1/4 of the velocity of the medium material, in order to get equivalent penetrations then fibre usage will be four times as much for the 1.4 micrometer material as it is for the 4.4 micrometer material and since the fine material costs about three times as much as the medium material does, the cost will be twelve times as great. Obviously a balance must be struck between filter cost and power cost.

CONCLUSION

The data presented in this paper points to the possibility that thin layers of fine fiber blankets, probably held on a substrate of coarse materials can serve as an efficient and cost effective filter. The thinner the 1.4 micrometer material can be made the higher the velocity for a given penetration and the lower the cost. If blankets of 1/4 and 1/8 inch thick material can be produced, then the operating costs will fall to those for 4.4 micrometer materials. Hopefully, the thinner 1.4 micrometer blankets will retain the advantages of reduced pressure drop and lower particle size cut-off points, when filtering smokes, of the thicker blankets.

Journal Article

1. Goldfield, J., V. Greco, K. Gandhi. Glass Fiber Mats to Reduce Effluents from Industrial Processes. APCA Journal, Vol. 20, No.7: 466-469, July, 1970.

FUNDAMENTAL EXPERIMENTS OF FABRIC FILTERS

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ABSTRACT

An experimental study of the fundamental performance of dust filter fabrics is carried out using a newly constructed bench scale apparatus. The pressure loss, the specific resistance, the particle collection performance, and the local penetration rate are examined as functions of the dust load on the fabric and the filtering velocity for several kinds of woven and felt fabrics, including one which has been used for a long period of time.

An experimental study of dust dislodging performance is also performed using a pilot scale pulse jet filter. Effects of the jet pressure, filtering velocity, number of the pulses, dust load on the fabric, and air humidity on the dust residue fraction are experimentally determined. The electrostatic charge generated by a cleaning pulse is presented as a function of the amount of dust load removed by a pulse jet.

INTRODUCTION

There are only a few fundamental studies of dust filter performance for a certain kinds of fabric under various operating conditions. An experimental study of filter fabric performance has herein conducted using a newly constructed bench scale apparatus, which is automated for operation and recording. A fundamental study of dust dislodging performance for a pulse jet fabric filter has also been carried out by use of a pilot scale apparatus with an inlet air humidifier. The experimental results provide useful information for the operation of a prototype fabric filter.

EXPERIMENTAL APPARATUS

Figure 1 is a schematic diagram of the experimental system of a filter fabric, which includes an automatic controller and recorder for the gas flow rate, recorders for the pressure loss and the particle concentrations, a particle size analyser, a constant dust feeder, a powder disperser, and an electrostatic neutralizer with a sonic ion generator. Shown in Figure 2 are the particle size distributions of various kinds of calcium carbonate test powder.

Figure 3 depicts an apparatus for measuring the dust dislodging efficiency of a pulse jet type. The humidity of inlet air can be automatically controlled by use of an absorption process.

EXPERIMENTAL RESULTS

3.1 Fundamental Studies of Filter Fabrics

3.1.1 Pressure Loss or Drag -

Given in Figure 4 is a comparison of the drags against the dust load on a woven fabric and a felt. It can be seen that the felt drag is proportional to the dust load, while the woven fabric does not have the same linear relationship. Figure 5 shows that the specific resistance of the dust layer increases with the filtering velocity, indicating that the dust layer is compressed to a greater extent at a higher pressure drop.

3.1.2 Collection Performance -

Shown in Figure 6 are a few examples of cumulative penetration against total dust load on various kinds of woven and felt fabrics at a low filtering velocity. The gradient of the straight lines are mostly minus unity, which means 100% collection efficiency. Figure 7 gives the cumulative penetration-dust load relationship for various filtering velocities. It can be seen that the collection performance deteriorates at higher filtering velocities. Given in Figure 8 is an example of local number penetration rate as a function of the dust load on a felt fabric. Subsequent to a drastic drop at about 20 g/m^2 dust load, the penetration increases slightly for a certain period, and then suddenly decreases again. The increase of penetration may be explained by the occurrence of pinholes in the dust layer due to higher pressure losses. Figure 9 gives the local penetration-dust load relationships of the same felt fabric for various ranges of particle size. It shows that larger particle size gives earlier decreases of the penetration. Figure 10 shows the local number penetration rates against the particle size at various dust load on a felt fabric. Given in Figure 11 is an example of the difference between the cumulative penetration and the instantaneous penetration at various dust loads on a felt fabric.

3.1.3 Comparison of Filter Performances Between a Virgin Fabric and Used One -

As shown in Figure 12, there is no significant difference in drag between a virgin woven fabric and a used one, which has been applied to an iron oxide fume of an electric arc furnace for the last three years, even though the dust adhered to the used fabric is not accounted as the dust load. Therefore the retained dust does not seem to locate in the air passages of the fabric. On the other hand, collection performances of the used fabric are usually better than those of the virgin one, as shown in Figure 13.

3.2 Dust Dislodging of Pulse Jet Type

Figure 14 shows that jet pressures of 4 Kg/cm^2 or higher are required for effective dislodging. The residue dust fractions based on the total collected amount are given as functions of the number of repeated pulses in Figure 15. It can be seen that it is better to repeat the pulse jets twice, though in the conventional device the pulse is usually activated only once for each cleaning cycle. Figure 16 shows the effect of the dust load on the residue dust fraction just after the cleaning pulse jet. The fraction of residue dust remains constant as the dust load is increased beyond 200 g/m^2.

The relative humidity of filtered air does not have much influence on residue fraction and specific resistance of dust layer on a felt fabric, as can be seen in Figures 17 and 18. Figure 19 shows the effect of relative humidity on the electrostatic charge generated by pulse jet cleaning for various dust loads dislodged from a felt fabric. The electrostatic charge has no linear correlation with the dislodged dust load. Therefore, it is not possible to estimate the amount of dislodged dust by use of the electrostatic charge or current for a cleaning pulse jet.

ACKNOWLEDGEMENT

We are grateful to Dr. K. Makino, Associate Professor, Department of Chemical Engineering, Kyoto University, Japan, for helpful suggestions.

Table 1. CHARACTERISTICS OF WOVEN FABRICS TESTED

Woven Fabric		PT 5101	PT 5111	PT 5201	PT 5203
Material		Tetron	Tetron	Tetron	Tetron
Weight [g/m^2]		253.7	184.3	429.3	314.4
Thickness [mm]		0.41	0.31	0.70	0.62
Apparent Density [g/cm^3]		0.619	0.595	0.613	0.507
Void [%]		55.1	56.9	55.6	63.3
Air Permeability[cm/sec]		31.3	34.5	9.8	29.0
Specific Resistance[1/m]		2.2×10^7	2.0×10^7	7.0×10^7	2.4×10^7
Yarn Construction	Warp	filament	filament	filament +spun staple	spun staple
	Filling	filament	filament	spun staple	spun staple
Yarn Count[/10cm]	Warp	556	300	284	288
	Filling	252	270	229	204
Weave		3/2 Twill	3/1 Twill	Sateen	Sateen

Table 2. CHARACTERISTICS OF FELT FABRICS TESTED

Felt Fabric	B 1400S	B 9400M	B 9500S	B 9640SF	Wool felt
Material	Polypropylene	Tetron	Tetron	Tetron	Wool
Weight [g/m^2]	420	406	523	640	560
Thickness [mm]	1.4	1.2	1.8	2.0	1.7
Apparent Density [g/cm^3]	0.300	0.338	0.291	0.320	0.329
Void [%]	67.0	75.4	79.0	76.8	-
Air Permeability [cm/sec]	22.0	23.9	23.2	15.0	16.5
Specific Resistance[1/m]	3.1×10^7	2.9×10^7	3.0×10^7	4.6×10^7	4.2×10^7

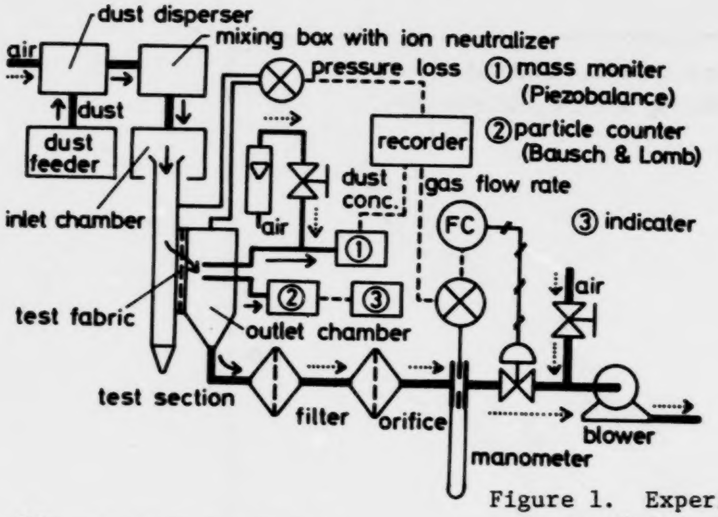

dust disperser
mixing box with ion neutralizer
air
dust
dust feeder
inlet chamber
pressure loss
① mass moniter (Piezobalance)
② particle counter (Bausch & Lomb)
recorder
dust conc.
gas flow rate
air
FC
③ indicater
①
②
③
air
test fabric
outlet chamber
test section
filter
orifice
manometer
blower

Figure 1. Experimental apparatus for studying performances of filter fabric

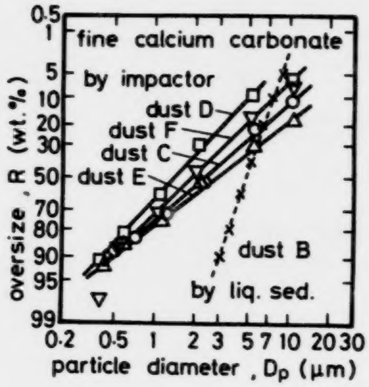
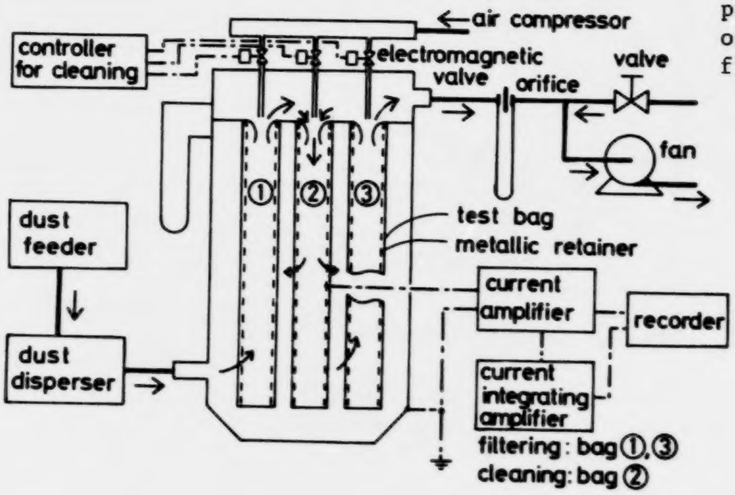


Figure 2. Particle size distribution of test dust by cascade impactor

Figure 3. Experimental pilot test apparatus of pulse jet fabric filter


air compressor
controller for cleaning
electromagnetic valve
orifice
valve
fan
①
②
③
test bag
metallic retainer
dust feeder
dust disperser
current amplifier
recorder
current integrating amplifier
filtering: bag ①,③
cleaning: bag ②

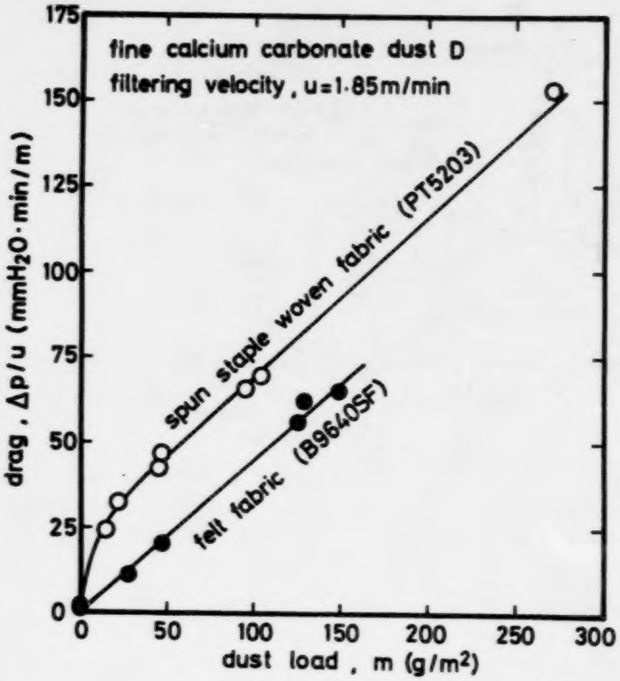


Figure 4. Correlations between drags and dust loads for a woven and a felt fabrics

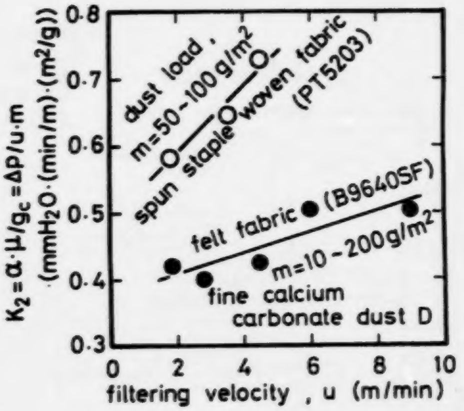


Figure 5. Relations between specific resistance α and filtering velocity for a woven and a felt fabrics

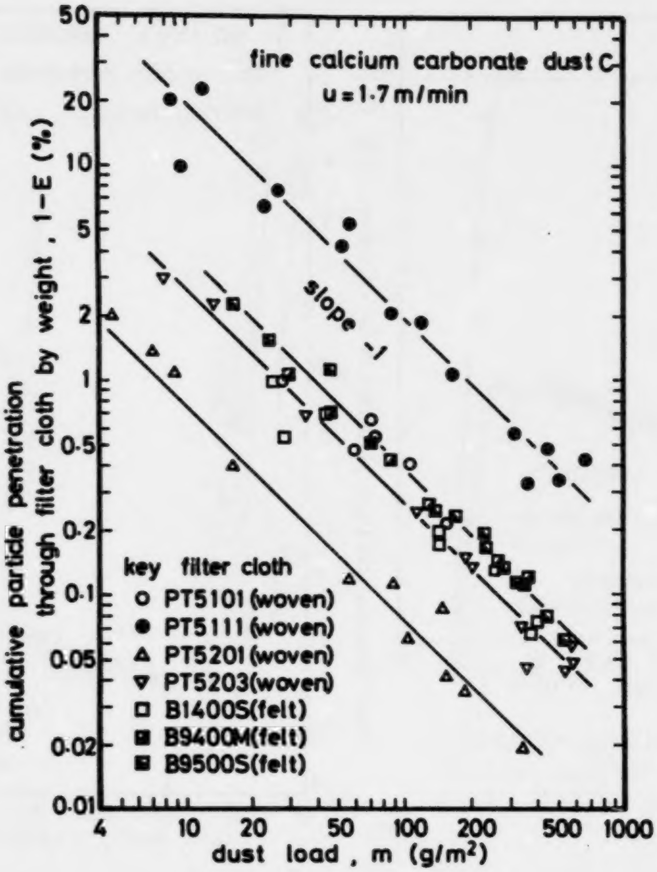


Figure 6. Relations between cumulative penetrations and dust loads for various woven and felt fabrics

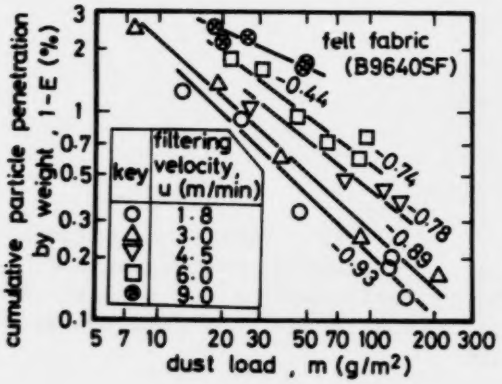


Figure 7. Effect of dust load on the cumulative penetration of fine calcium carbonate D at various filtering velocities

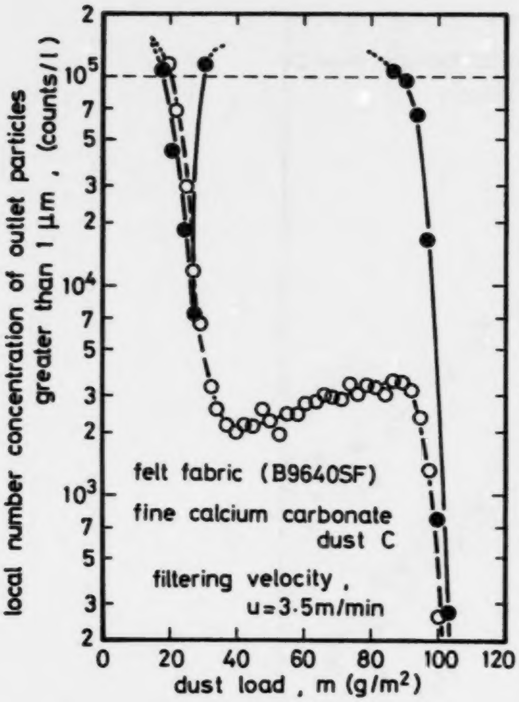


Figure 8. Relations between local penetration rate and dust load on a felt fabric

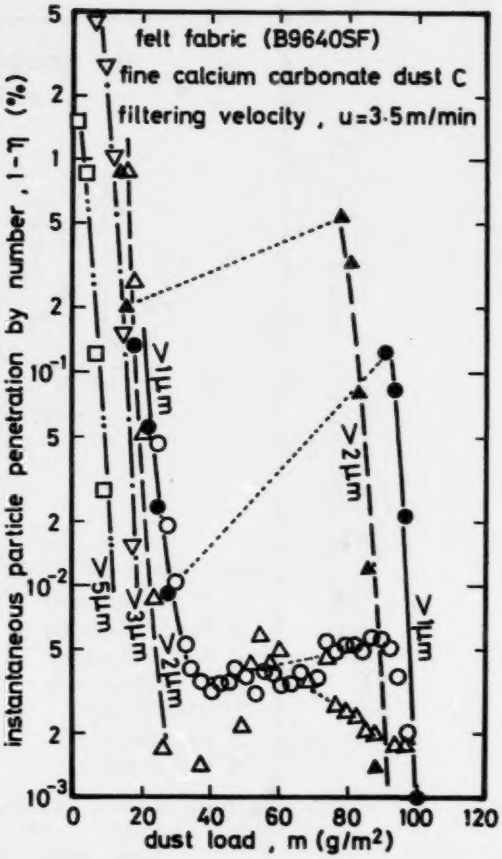


Figure 9. Relations between local penetrations and dust load for various particle size ranges

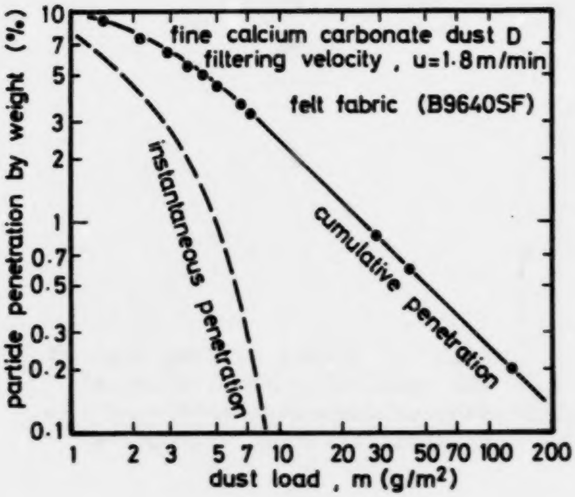


Figure 11. Difference between cumulative penetration and instantaneous one at various dust loads on a felt fabric

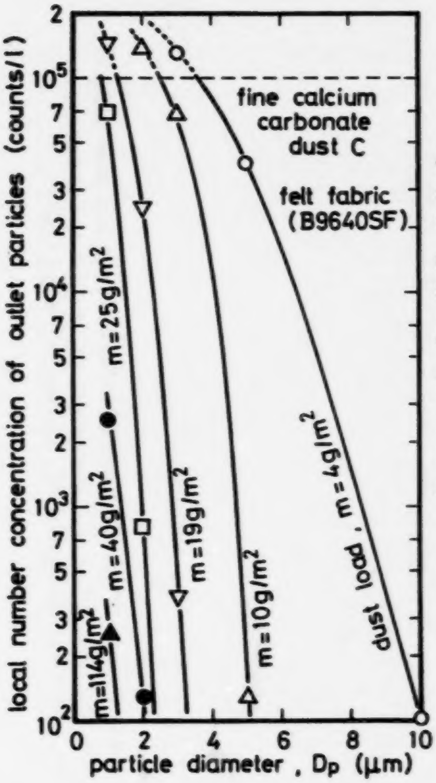


Figure 10. Relation between local penetration and particle size at various dust loads on a felt fabric

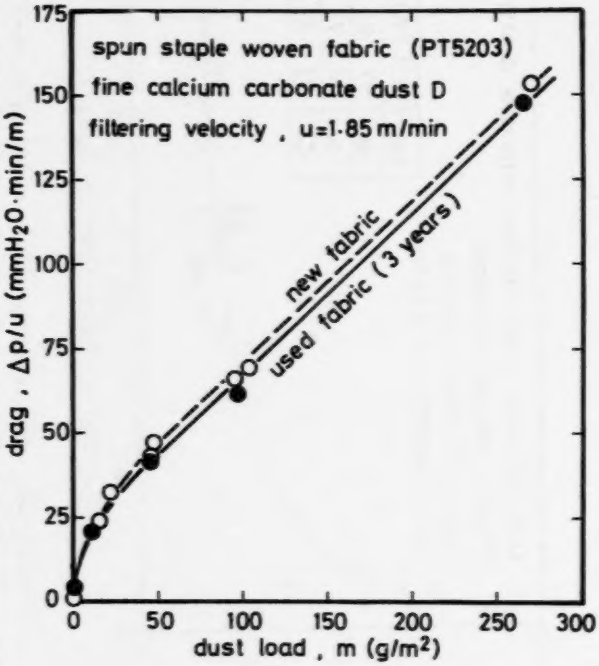
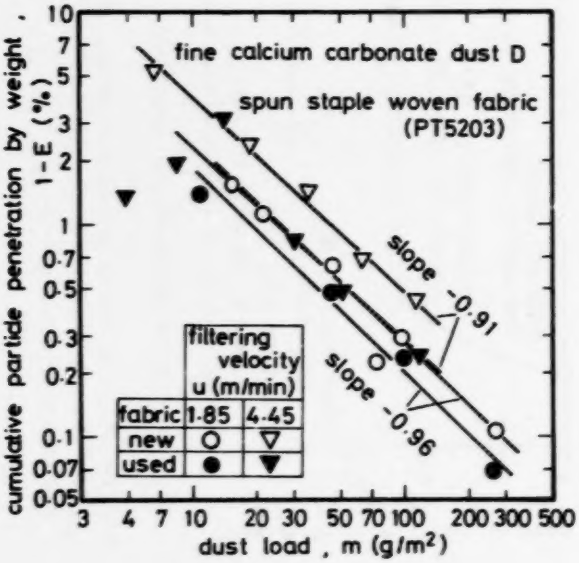


Figure12. Comparison of drags against dust load between a virgin woven fabric and a used one

Figure 13. Particle penetrations of a virgin woven fabric and the used one against dust load



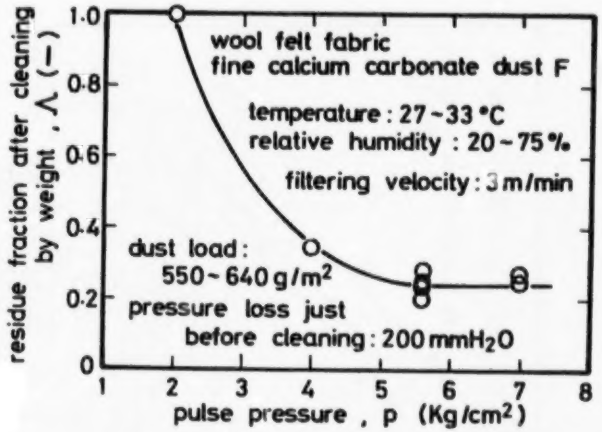


Figure 14. Relation between residue dust fraction on a felt fabric and pulse jet pressure

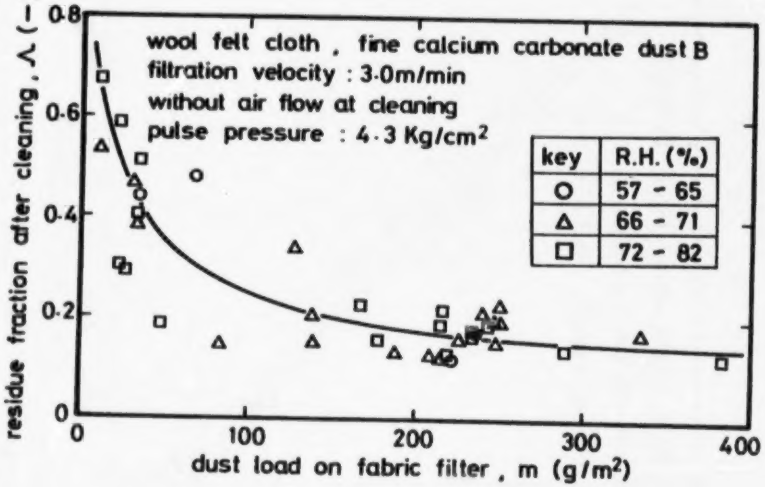


Figure 16. Relation between residue dust fraction and dust load on a felt fabric

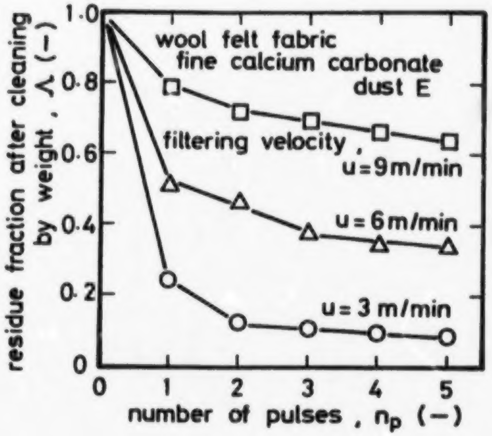


Figure 15. Relations between residue dust fraction and number of repeated pulses for a felt fabric at various filtering velocities (RH=64%, temp.=18°C, press.=5.6 kg/cm^2)

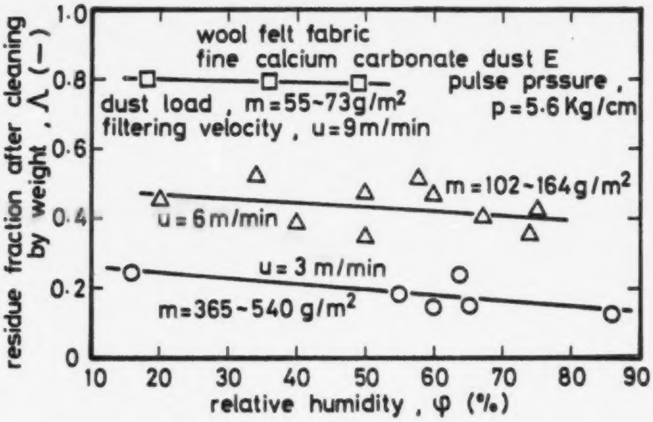


Figure 17. Relations between residue dust fraction and relative humidity for a felt fabric

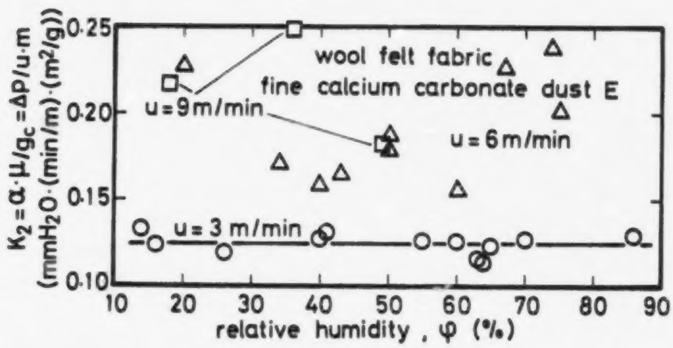


Figure 18. Relation between specific resistance and relative himidity for a felt fabric

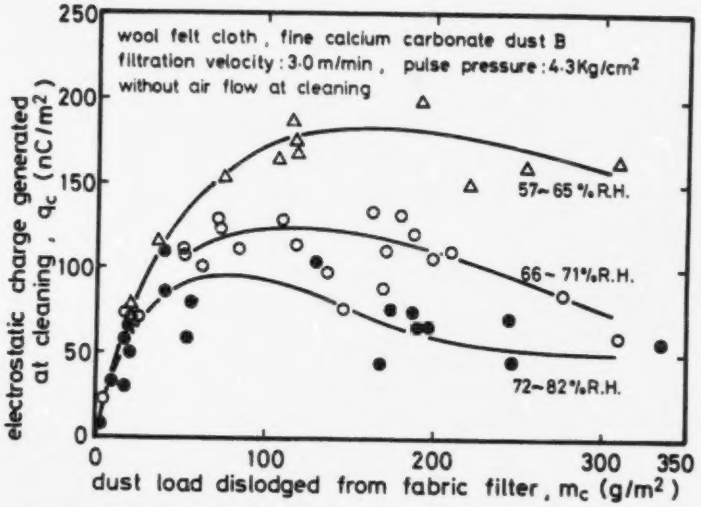


Figure 19. Effect of relative humidity on generated electrostatic charge for various dislodged dust load from a felt fabric

A DUAL PURPOSE BAGHOUSE FOR PARTICLE CONTROL AND FLUE GAS DESULFURIZATION

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INTRODUCTION

The U. S. Environmental Protection Agency has promulgated a series of regulation limiting the allowable effluent from all types of industries. As these regulations become effective, they place an increasing demand on industry to develop innovative technology to meet the effluent limitations in a cost-effective manner. The power generation industry and other large coal users in the western half of the United States experience a particularly difficult control problem due to the specific characteristics of western coal. This paper describes a technique to control both the particle and the sulfur dioxide emissions from a new, western coal-fired power generating station to within the limitations set forth in the Federal New Source Performance Standards as currently enforced and as currently proposed by the Office of Air Quality Planning and Standards.

Baghouses have been used for many years to effectively control the particle emissions from western coal-fired power plants. The alternative control devices, electrostatic precipitations, have proven to be somewhat less effective on western coals due to the low resistivity of this fly ash.

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Several recent test programs have demonstrated that by pre-coating the traditional baghouses with a dry solvent material, a reduction in sulfur dioxide emissions can be achieved, thus enabling both particulate and SO_2 control with a single device. A dual purpose baghouse was developed by Lutz, et al.,[1] utilizing this process to control both particle and sulfur dioxide emissions to the requirements of the Federal New Source Performance Standards.

REVIEW OF NEW SOURCE PERFORMANCE STANDARDS

Section III of the Clean Air Act Amendments of 1977, to the 1970 Clean Air Act gives the EPA the authority to establish standards of performance for new and modified stationary sources. New plants must meet the New Source Performance Standards (NSPS) applicable at the time of construction. The NSPS for sulfur dioxide is currently being revised with a new standard expected by the end of this year. The standards applicable to fossil fired power plants are as follows.

Particulate Removal Requirements

Federal NSPS regulations limit the emissions of particulate matter to 10 pounds per 10^6 BTU heat input based on a two hour average. Additionally, the opacity from these plants is limited to 20 percent opacity, except that 40 percent opacity shall be permissible for not more than two minutes in any hour.

SO_2 Emissions Limitations (Existing)

Existing federal regulations concerning the SO_2 emissions from a fossil-fired power generation station are based on an allowable emission rate which is proportional to the power output of the plant. The regulation is:

1.2 pounds SO_2 per 10^6 BTU heat input to the boiler

SO_2 Emissions Limitations (Proposed)

The EPA is currently revising the NSPS for SO_2 at fossil field power generation stations. Although the final form of these requirements are not now known, the current draft of these requirements is:

- 85% SO_2 removal on a 24-hour average which can be exceeded for not more than 3 days per month.
- 75% SO_2 removal minimum allowable for these 3 days.

The above standards shall not require removal of SO_2 to a level less than 0.2 pounds SO_2 per 10^6 BTU heat input. An emission ceiling of 1.2 pounds SO_2 per 10^6 BTU heat input shall not be exceeded more than 3 days per month.

REVIEW OF SO_2 AND PARTICLE REMOVAL IN BAGHOUSES

Many tests have been performed which demonstrate the capability of a variety of dry materials to remove SO_2 from a gas stream. The most promising of these dry materials is nahcolite, which is found in conjunction with oil shale deposits in the Green River formation of northwestern Colorado. It is a naturally occurring ore with a typical assay of 70 percent sodium bicarbonate. Dry process desulfurization with nahcolite involves the reaction of $NaHCO_3$ and Na_2CO_3 contained in the nahcolite ore with the SO_2 in the flue gas stream. This reaction is maintained by pre-coating the bags with crushed nahcolite prior to placing them on line, and by injecting additional nahcolite into the gas stream ahead of the baghouse. SO_2 removal efficiencies of between 30 and 95 percent have been reported from various test facilities.

Particle removal by baghouses are well known. Efficiencies of between 99.8 and 99.9 percent have been demonstrated for particles in the 1 to 10 µm size range at several operating facilities.

FACTORS EFFECTING SO_2 REMOVAL EFFICIENCY

Sizing of Injected Sorbent

The speed with which the $NaHCO_3$ is decomposed into Na_2CO_3 is clearly a direct function of particle size, with the finer materials decomposing at a significnatly faster rate. This decomposition rate acts to limit the rate of reaction of SO_2 with nahcolite within a fixed bed of sorbent. To prevent this consideration from limiting the required efficiencies, it is necessary to maintain the sorbent size below a certain maximum particle diameter. Based on tests by the Superior Oil Company at the Cherokee Station of Public Service of Colorado, it is necessary to provide the nahcolite at approximately -200 mesh.

Stoichiometric Ratio

Stoichiometric ratio is determined by the amount of nahcolite used to react with a fixed amount of SO_2. A ratio of 1.0 provides the exact amount of sorbent to react fully with the SO_2 present if the reaction were allowed to go to completion. In practice, ratios of between 0.5 and 2.5 are used, with the larger ratios providing greater efficiencies but requiring a greater amount of nahcolite, thus increasing cost.

Temperature of Reaction

There is a very strong dependence of removal efficiency on the gas temperature at the reaction site. Figure 1 illustrates this relationship. Increasing the gas temperature dramatically increases the reaction rate, especially within the temperature range of 250° to 600°F. To maintain a specified removal efficiency, the stoichiometric ratio can be reduced if the temperature is increased by a corresponding amount. This effectively reduces the amount of sorbent material required per ton of coal combusted, but increases the size and hence the capital costs of the baghouse and related duct work due to the greater volume that the gas occupies at the elevated temperatures.

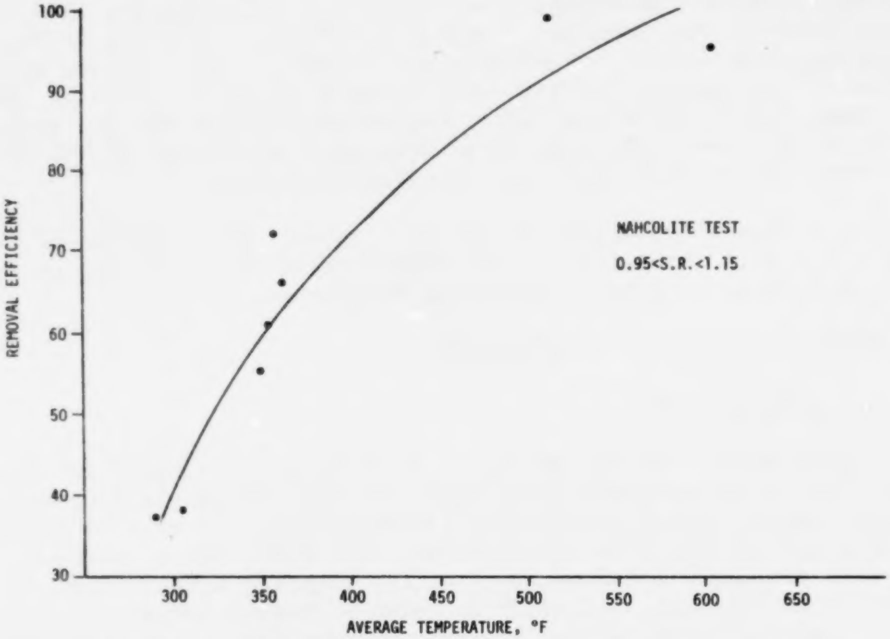


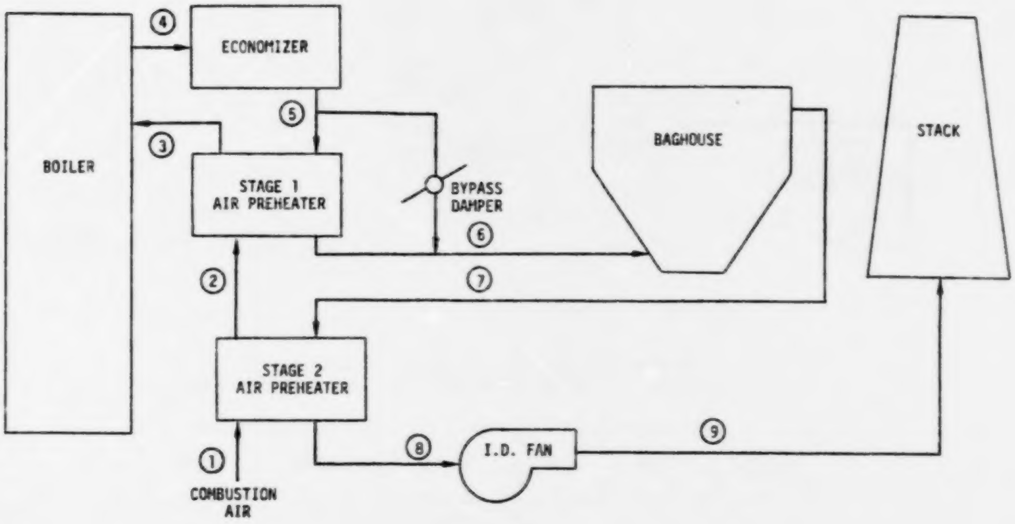
FIGURE 1 - EFFECT OF TEMPERATURE ON REMOVAL EFFICIENCY

Contact Time

Liu, et al.[2], found that there was a definite advantage by injecting the additive further upstream of the filter house to increase retention time. The maximum removal efficiency can be obtained with a combination of filter bag pre-coating and upstream injection of the nahcolite. To prevent possible equipment damage due to the high particle load of the flue gas stream containing both fly ash and nahcolite, the injection point for the sorbent should not be upstream of any air preheater or other flue gas handling equipment.

PROCESS DESIGN

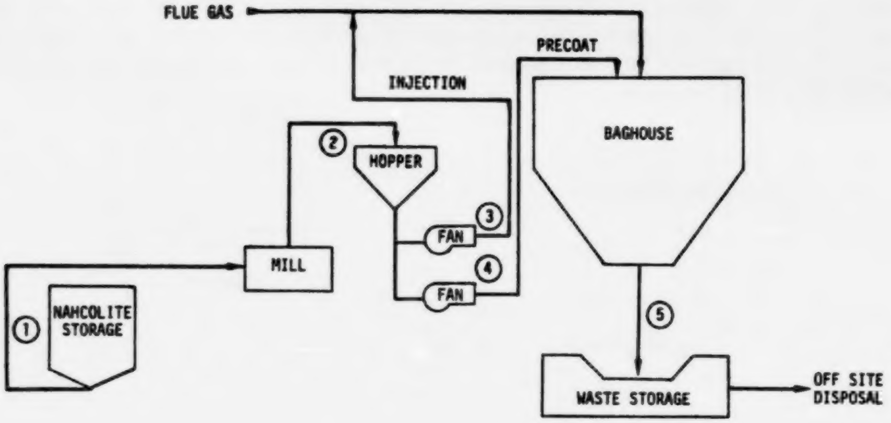
Lutz, et al.[1], developed an optimized system design for western coal-fired power generating stations which meets the present NSPS requirements for particle and sulfur dioxide emissions. Figure 2 presents the flue gas side process flow chart for this design. The significant difference between this design and the typical particle control baghouse is the use of a two-stage air preheater to allow the baghouse to be operated at an elevated temperature. A bypass is included around stage 1 of the air preheater to enable the required baghouse temperature to be maintained when the power plant is operated at less than design load. This baghouse reflects a design to handle 1.5 x 10^6 acfm of flue gas at 400°F with an air to cloth ratio of 3:1 and a stoichiometric ratio of 1.0. This design provides an SO_2 removal efficiency of 70 percent which is the required removal efficiency to meet the current NSPS for a typical western coal with a 1.0 percent sulfur content, 10 percent ash content, and 10,500 BTU per pound heating value.



	1 COMBUSTION AIR INLET	2 COMBUSTION AIR TO STAGE 1 AIR PREHEATER	3 COMBUSTION AIR TO BOILER	4 BOILER FLUE GAS	5 ECONOMIZER OUTLET	6 FLUE GAS TO BAGHOUSE	7 FLUE GAS FROM BAGHOUSE	8 I.D. FAN INLET	9 FLUE GAS TO STACK
TEMPERATURE (°F)	110	292	655	890	705	400	375	225	225
FLOW (10^6 lb/hr)	4.0	4.0	4.0	4.3	4.5	4.7	4.7	4.9	4.9

FIGURE 2 - FLOW CHART (FLUE GAS)

Figure 3 represents the process flow chart for the nahcolite handling system for this same design case. Nahcolite is assumed to be delivered by unit trains, with on-site storage for 35 days. Nahcolite is stored in covered hoppers and all transfers/conveying systems are of the preumatic conveying type. The waste material silo is sized to accommodate 300,000 cubic foot of combined sorbent/fly ash material, which will allow an accumulation of 5 days worth of operation without disposal. The waste material is assumed to be disposed of by dry landfill within clay isolation cells.


FLUE GAS
PRECOAT
INJECTION
BAGHOUSE
②
HOPPER
③
FAN
MILL
④
FAN
①
NAHCOLITE STORAGE
⑤
WASTE STORAGE
OFF SITE DISPOSAL

	1 CRUSHED NAHCOLITE	2 MILL OUTLET	3 NAHCOLITE TO INJECTION	4 NAHCOLITE TO PRECOAT	5 SPENT ABSORBENT/ FLY ASH
FLOW (lb/hr)	30,000	30,000	24,000	6,000	64,400

FIGURE 3 - FLOW CHART (SOLIDS HANDLING)

Projected costs for this combined particle and sulfur dioxide control system were established based on a construction midpoint of February, 1977 and are given in 1977 dollars:

Nahcolite Unloading	$ 5,350,000
On-Site Storage	2,023,600
Conveyors	170,600
Surge Tank	84,400
Mill Area Conveyors	138,500
Mill	419,000

Storage Tank	$ 73,800
Injection to Ducts	37,000
Injection to Baghouse	37,000
Baghouse	10,068,300
ID Fans	1,152,300
Ducts	288,400
Ash Conveyors	74,700
Ash Disposal Storage	765,000
Waste Disposal	87,400
Total Capital Cost	$22,755,000

Annual operating costs were established as $9,102,900. This cost assumes a unit price for nahcolite of $32.50/ton, and an annual charge of 14.9% of the total capital investment.

HIGH EFFICIENCY SYSTEM

The NSPS standards currently proposed for fossil-fired generating stations will reduce the allowable SO_2 emissions by requiring reduction by 85 percent, except for those plants which will fall below the lower emissions limit by burning extremely clean coal. Limited test data at this level of SO_2 reduction efficiency indicates that this level of emission reduction is achievable with a dry sorbent baghouse system. Baghouse temperatures must be boosted to approximately 500° to 550°F and the stoichiometric ratio will have to be increased, both resulting in an increase of capital and operating costs. Most test data on the dry sorbent baghouse system has been obtained at operating temperatures below 500°F because of the greater availability of test facilities meeting this condition. Additional test data at the higher temperatures must now be obtained to confirm the design conditions prior to the commitment of this design for the new proposed NSPS. Combined systems, such as a 70 to 80 percent removal dry sorbent baghouse coupled with a coal cleaning operation may also be considered. Cavalaro[3], evaluated the coal cleaning potential of various American coals and established the potential SO_2 emissions reductions as 29 percent for western midwest region coal and 12 percent for western region coal.

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SIMULTANEOUS ACID GAS AND PARTICULATE RECOVERY

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ABSTRACT

Simultaneous particulate and acid gas collection is achieved by the nucleation and chromatographic processes. Commercial installations in the fiberglass, glass, jet engine, secondary aluminum, pulp and paper, fertilizer, and incineration industries confirm the effectiveness of the processes. The characteristics of the emissions from these systems are

Emissions	Nucleation	Chromatographic
Particulate GM/NCM	0.02-0.05	0.0002-0.02
Gaseous PPMV		
HF	<1	<1
$HC\ell$	<1	<1
SO_3	<1	<2
SO_2	<1	<40
Opacity	<10%	ZERO
Pressure Drop Requirements mm H_2O	25-250	100-200

Emissions from industrial processes normally contain both particulates and gaseous pollutants. Inasmuch as there are interpendent effects, separation of removal concepts may not always be feasible.

Examples of the types of contaminants to be recovered in industrial emissions are indicated in Table 1.

In all cases, the recovery of both the particulate and gaseous emissions can be conducted simultaneously. In three cases the contaminants are recovered in a form and composition permitting recycle to the manufacturing process, reducing use of raw materials and obviating the disposal problem.

Although the concentration of the particulates can vary widely in the emission stream in any single process, it has been our experience that while the concentration has an effect on the mode of collection, the major concern in design is the particle size cut point. The modes of particulate recovery accompanied by gaseous component recovery were therefore developed on the cut point criterion with capability for response to variation in loading. The collection processes utilized are

1 - nucleation with simultaneous absorption

2 - chromatographic absorption and low energy inertial impact.

NUCLEATION-ABSORPTION

Nucleation-absorption[1,2,3], the simultaneous collection of particulates and gases, is generally conducted in cross-flow or cocurrent regime to optimize the kinetics of absorption accompanied by chemical reaction and to provide adequate liquid irrigation for removal of the captured particulates.

The particulate collection by the nucleation process is based on four mechanisms when conducted with hydrophilic materials.

1 - condensation of water on the particulates at or above the dew point

2 - agglomeration of the particulates by inelastic Brownian interception

3 - short path inertial impact on small targets

4 - thermophoretic collection in short paths to small target surfaces.

Where hydrophobic particulates are to be collected, the simultaneous condensation on a significant population is not achieved[4]. Application of either inherent vibrational energy enhances the Brownian agglomeration[2] or a sequential condensation-vaporization mechanism is imposed[3] to overcome the limited population wetting.

Where the inherent surface charge on the particle exceeds 10^{12}-10^{13} ergs/cm^2 and where the surface of the particle contains radii of curvature less than 80°, condensation can occur at or above the dew point (Fig. 1). In practice, it has been found that the kinetics of isothermal nucleation is highly dependent on the population density of the water molecules) with a desirable level above 25% by volume[1]. The thermophoretic contribution is indicated in Fig. 2.

A critical factor in the efficiency of the nuleation process is the provision for short path inertial and thermophoretic capture. In commercial application, the "growth" occurs within an irrigated packed bed where the average inertial or diffusional path is of the order of 3 mm combined with a 2 mm "target."

The energy loss for the combined nucleation absorption system varies between 50 mm H_2O and 300 mm H_2O as a function of total process demands.

Inasmuch as the particulate collection occurs in a packed bed (crossflow or cocurrent), absorption is conducted simultaneously. Some of the systems employing these mechanisms and their performance are indicated in Table 2 and Figs. 3, 4.

Table 1. TYPICAL EMISSIONS FROM PROCESSING

	PARTICULATE			GASES	
Process Source	Composition	Size Micron	Loading GM/NCM	Composition	Conc. PPMV
Fiberglass	Na_2SO_4, NaF B_2O_3, H_3BO_3	0.05-2	0.2-0.6	HF SO_2, SO_3	200-400 200-400
Secondary Aluminum	C, oil $A\ell_2O_3$ $A\ell F_3$, $A\ell C\ell_3$	0.05-30	0.02-0.4	$HC\ell$, $C\ell_2$, HF, SO_2, SO_3	5-100
Recovery Boiler Pulp and Paper	Na_2SO_4 Na_2CO_3	0.2-3	0.8-4	TRS SO_2	10-2000 50-1500
Fertilizer DAP, MAP	P_2O_5 DAP $NH_4F \cdot HF$	0.1-3	0.05-0.3	HF, SiF_4 NH_3	100-30000 100
Jet Engines	C, oil	0.04-0.2	0.02-0.3	SO_2	<50
Municipal Incinerators	SiO_2, PbO ZnO, $A\ell_2O_3$ C, oil	0.1-20	0.8-4	$HC\ell$ HF	0-600 0-50

Table 2.

COMMERCIAL NUCLEATION PROCESS APPLICATIONS

	GAS INLET CONDITIONS							GAS OUTLET		System ΔP in. w.g.
			PARTICULATE			GASES				
APPLICATION	Flow ACFM	Temp°F DB/DP	Type	GM/NCM	Size Microns	Type	Conc. PPM	PART. GM/NCM	GAS PPM	
RECOVERY BOILER SO_2 - Particulate	200,000	300/160	Hydrophilic	0.8-2	0.2-3	SO_2	1500	0.06-0.13	<1	11
RECOVERY BOILER TRS - Particulate	150,000 -300,000	300/160	Hydrophilic	0.7-3.5	0.2-3	TRS SO_2	<1500 <300	0.03 -0.07	<10 <3	13
FERTILIZER HF, SiF_4 - Particulate	20,000 -100,000	170/150	Hydrophilic	0.05-0.3	0.05-3	HF SiF_4	<1500 <1500	~0.01	<3 <1	6
JET ENGINES SO_2 - Particulate	500,000- 3,000,000	1200	Hydrophobic	0.02 -0.3	0.04- 0.2	SO_2	<50	0.004 -0.009	<3	2
ORG. CHEM. INC. $HC\ell$ - Particulate	150,000	1500	Hydrophilic Hydrophobic	0.1- 0.6	0.02 -10	$HC\ell$	~2000	<0.02	<10	6

CHROMATOGRAPHIC

Many industrial emission sources emanate from processes involving only dry material handling. Imposition of wet scrubbing for particulate and gas recovery requires the acquisition of new skills and oftentimes, secondary water treatment.

Recovery of pollutants in dry form with the potential of recycle of the captured materials is therefore desirable in these cases.

The use of solid reagents injected into a gas stream for gas adsorption-absorption has been well established. The reaction, however, if achievable, is generally limited to surface molecules, if the stream conditions permit effective reaction. Thus a major portion of the reagent is unused. Where hot streams are encountered, permitting water quenching, the reagent may be dissolved or suspended in the quench water such that a greater portion of the reagent can react. However, the problem of wet bottoms in these evaporative reactors has been encountered, resulting in low system reliability.

Generally, the submicron and oily particulates suspended in the gas stream pass through to the final collector unaffected and can result in blinding and solids buildup problems.

The chromatographic process[5,6,7] utilizes any of three basic components or combination thereof as a function of the severity of the problem. The mechanisms are as follows:

a - gas absorption on a chromatographic surface
b - gas absorption in a quench reaction
c - particulate capture in a low energy dry venturi
d - total mass recovery in a gross collector.

a - The kinetics of absorption accompanied by chemical reaction on thin surface layers is generally an order of magnitude greater than the comparable process of liquid phase absorption. It is noted, Fig. 5 that the mass transfer coefficient for absorption of CO_2 on a termolecular layer of diethanolamine ranges from 50-550 in the English unit system compared with 0.01-1 for liquid-gas contactors.

The reasons for this great increase in the kinetics of the process are the circumvention of diffusion in the liquid phase, generally the rate controlling process[8] and the van der Waal activation of the surface molecules.

The limitation of this process is capacity.

However, in many cases of pollution control, the quantities of contaminant gases to be absorbed are of a magnitude permitting economic use of the chromatographic material.

In some cases an adduct rather than a compound is formed, permitting regeneration of the chromatographic material.

The efficiency of acid gas recovery by chromatography is relatively insensitive to gas velocity because of the high rate of absorption-reaction.

b - Where the quantity exceeds the capacity of the economic use of the chromatographic material, and the gases to be treated are hot, a direct reaction can be utilized in a quench reactor. The problems encountered in quench reaction are "wet bottoms" that can cause severe disruption in operation and low utilization of the reagent. This is often reflected in excessive "safe" size of equipment.

A new type of quench reactor has been developed utilizing "mist reaction" and a new flow orientation. This has resulted in smaller equipment, increased utilization of reagent of the order of 1.5 times stoichiometric, and prevention of the occurrence of "wet bottoms."

c - Even where reaction occurs, a major problem is the survival of the submicron particulates. If they reach the final gross collector, generally a baghouse, in an unagglomerated state, the cleaning cycle time is reduced and the residual pressure drop increases. These factors adversely affect the economics and reliability of the system.

In order to minimize the survival of submicron particulates, a "dry venturi"[9] was developed to provide for capture of the submicron particulates at low energy consumption prior to admission to the baghouse.

The dry venturi (Telroy) system does not require any increase in gas velocity beyond normal duct flow rates. Instead, the target size injected into the system is of the order of 10 microns. A comparison of projected performance utilizing inertial impact relationships[10] is indicated in Table 3.

As noted in the chart the dry venturi has an efficiency equivalent to a 2000 mm H_2O (~80 in.) venturi at an energy expenditure equivalent to 15 mm H_2O (~0.6 in. w.g.). This has been confirmed in field performance where the collected material could not be separated by fractional elutriation and pressure drop buildup (in the baghouse) was extremely slow.

The final collection of the agglomerated particulate containing the neutralized gas is captured in a baghouse or equivalent device.

As a result of the introduction of the procedure, baghouse shake cycles for the continuous chromatographic injection are of the order of 24 to 48 hours with total inlet particulate loadings of the order of 2 gm/NCM. In addition, pressure drop rise is quite slow, of the order of 0.2-1 mm H_2O/hr.

Where the particulate and gas loads are low or are variable with a low average value, the system may be operated in a batch regime where the chromatographic material is used as a precoat in the baghouse. In this mode of application in the secondary aluminum industry, the shake cycle is of the order of 3 to 7 days as a function of loading.

The performance of these systems are indicated as follows:

1 - Continuous system performance data including quench reactor, dry venturi (Telroy), chromatographic absorption, baghouse Table 4, Fig. 6 .

2 - Batch system performance Table 5, Figs. 7.

The application of the Nucleation and Chromatographic systems in the control of industrial emissions have achieved simultaneous or sequential recovery of both fine particulates and contaminant gases. Reduction of submicron particulate emissions below levels of 0.02 gm/NCM coupled with opacities below 10% and simultaneous recovery of gaseous pollutants as well as thermal values has been demonstrated on a commercial scale.

Table 3. COMPARISON OF PREDICTED CAPTURE PERFORMANCE

WET VENTURI AND DRY VENTURI

PARTICLE SIZE CAPTURED MICRONS	WET VENTURI		TELROY DRY CAPTURE	
	ΔP mm H_2O	EFFICIENCY PER CENT	ΔP mm H_2O	EFFICIENCY PER CENT
0.3	250	54-64	15	85-90
	630	72-78		
	1250	80-86		
	2000	82-90		
0.5	250	77-80	15	92-95
	630	84-90		
	1250	88-95		
	2000	92-99		
1.0	250	88-95	15	99-100
	630	94-100		
	1250	96-100		
	2000	100		

Table 4. FIBERGLASS EMISSION CONTROL

CHROMATOGRAPHIC SYSTEM

EIGHT MONTH PERIOD

Inlet Conditions

HF	150-350 PPMV
SO_x	200-400 PPMV
Part.	0.25-0.6 GM/NCM (exc. of boron)
Boron	0.06-0.25 GM/NCM

OUTLET CONDITIONS

RUN NO.	PARTICULATE GM/NCM	FLUORIDE GAS PPMV	BORON GM/NCM	SO_x PPMV
47	0.012	1.3	0.0035	22
49	0.003	0.05	0.0028	32
54	0.014	0.18	0.0046	60
57	0.010	0.35	0.0017	25
58	0.006	0.16	0.0012	
66	0.004	0.40	0.0021	
73	0.006	0.80	0.0016	55

5. CONTAINER GLASS TESTS

SO_3 REMOVAL
(Precipitation Tests)

PPM SO_3	
INLET	OUTLET
25.6	0.45
35.3	0.64
30.1	0.45
25.6	0.21
28.3	2.1

Los Angeles APCD
TESI System

Table 6. ALLIED METALS

CITY OF CHICAGO DATA

PARTICULATE

	1973 Uncontrolled		1977 Teller System	
	GR/DSCF	SCFM	GR/DSCF	SCFM
CHARGING	0.020	31,400	0.00008	25,600
	0.045	31,900	0.0002	25,600
	0.126	32,400	0.0003	25,600
			0.0004	25,600
			0.0003	25,600
DEMAGGING	0.079	26,600	0.0001	26,000
	0.020	26,400	0.0013	26,000
	0.026	26,500	0.0015	26,000
			0.0005	26,000
			0.0007	26,000

FLUORIDE GAS

	PPM	LB/HR	PPM	LB/HR
DEMAGGING	180	15.2	2.8	0.28
	595	49.9	1.6	0.16
	44	3.7	1.2	0.12
			1.2	0.12
			1.2	0.12

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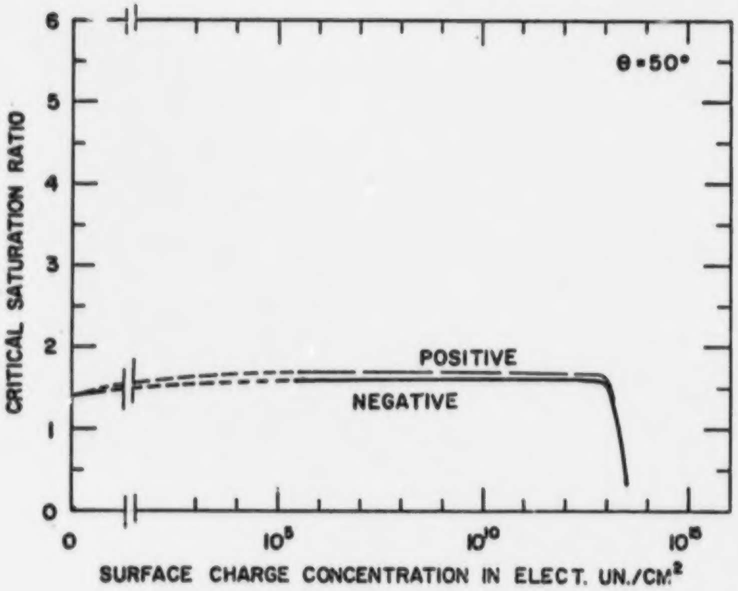

Figure 1: Variation of the critical saturation ratio as a function of the density of charge (negative and positive), for water vapor nucleation upon plane substrate, at 273 degrees K and contact angle of 50 degrees.

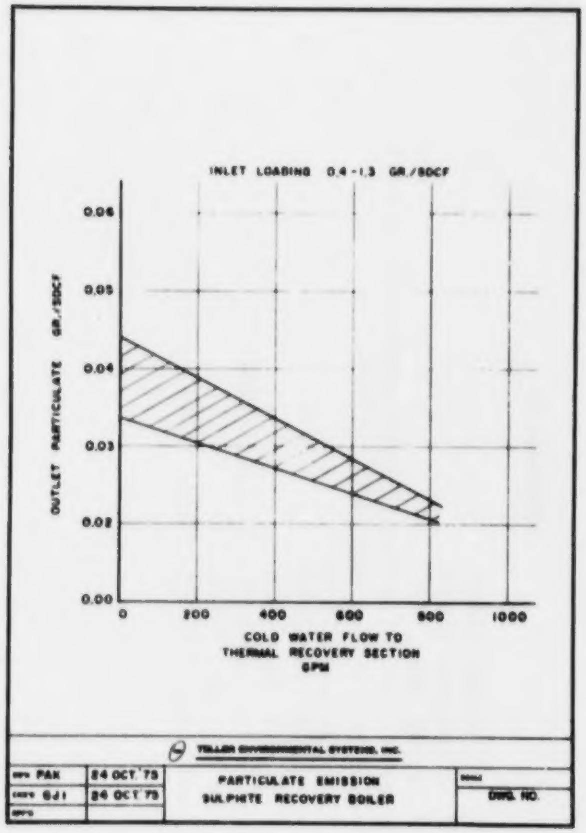

Figure 2

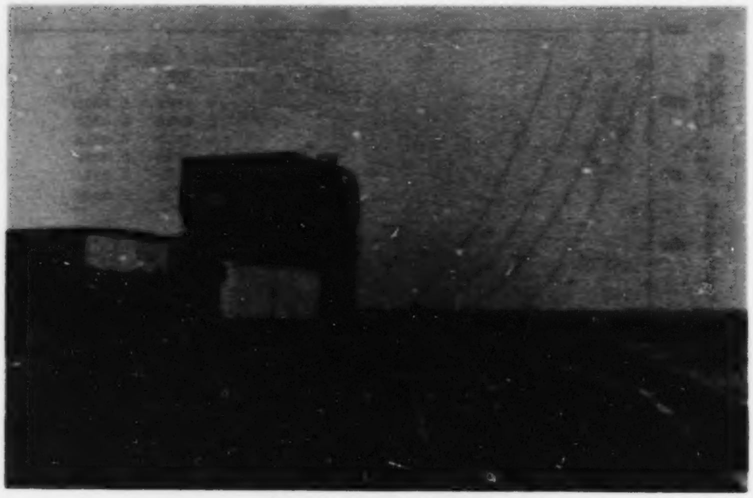

Figure 3: Jet engine test cell nucleator.

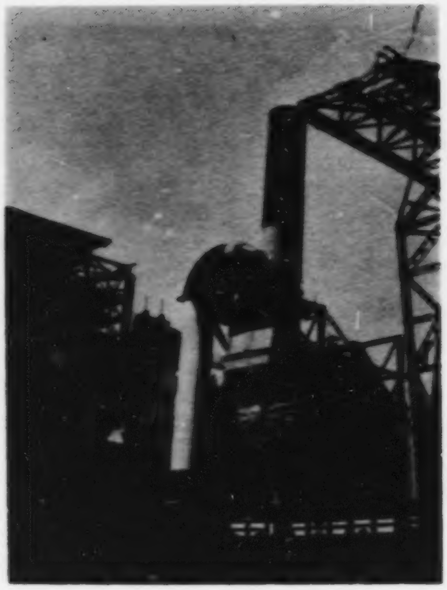

Figure 4: Recovery boiler - nucleator.

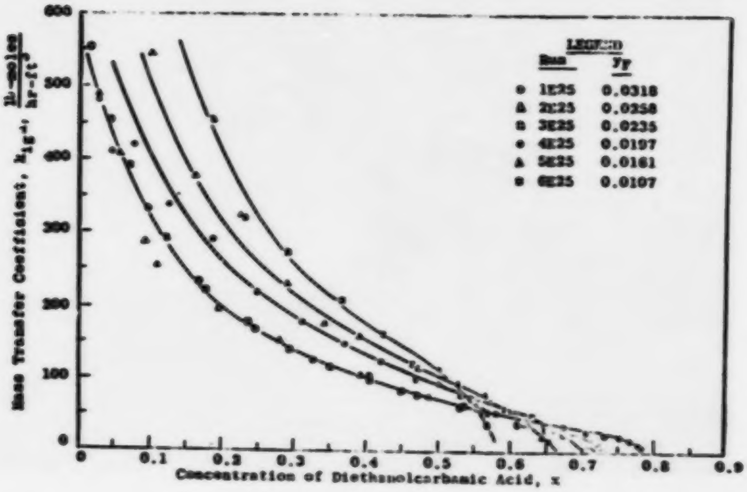

Figure 5: Variation of $k_{ig}a$ with degree of absorption and feed composition; $P \cong 1$. CO_2 - DEA chromatographic system.

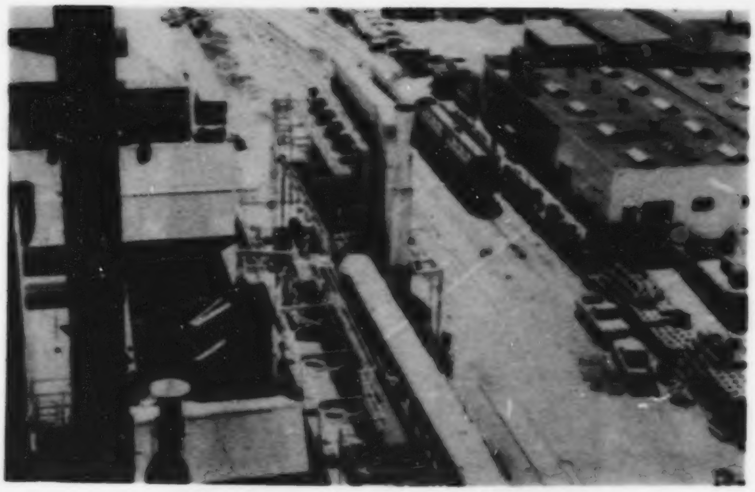

Figure 6: Glass furnace - chromatographic system.

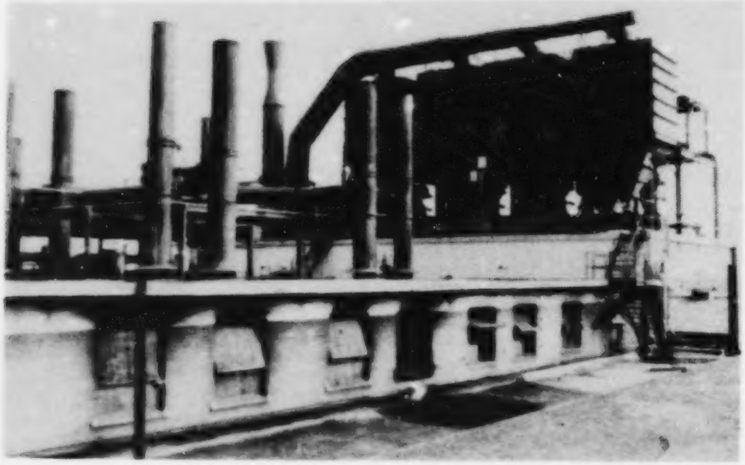

Figure 7: Secondary aluminum - chromatographic system.

TECHNOLOGY OF FIBER GLASS FILTER FABRIC DESIGN

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ABSTRACT

The performance of a fiber glass filtration fabric in high temperature fabric collectors can be influenced by fabric design. This paper investigates design variables of fiber glass filter fabrics, such as yarn construction (unplied yarns vs. plied yarns), fabric count, weave patterns and fabric finishes. Test data on fabric properties as a function of these variables is given for correlation with fabric performance as a filtration media.

INTRODUCTION

Although fiber glass fabrics have been used in high temperature filtration for approximately twenty years, little has been published on the influence of fabric variables on fabric properties relating to its performance as a filtration media.

The results of an extensive investigation are presented herein in order to assist engineers in selecting and specifying fiber glass fabrics for their filtration requirements.

BACKGROUND

Fabrics are essentially bidirectional planar structures, with properties determined by the amount (count) and type of yarn woven in the warp (lengthwise) and filling (crosswise) directions. Filtration fabrics are also influenced by the manner in which the warp yarns and filling yarns are interlaced (weave pattern).

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texture or bulk to the yarn.

Yarn technology has advanced to where singles yarn can be texturized and woven, hence eliminating the cost of plying yarn prior to texturizing. Consequent economic advantages are obvious.

Singles Yarn vs. Plied Yarn

The economic advantages of current singles yarn technology, whether continuous filament or textured yarn, would be meaningless unless the resultant fabric exhibited equal or improved performance over comparable plied yarn fabrics.

Therefore, two standard commercial fabrics (Style 823 and Style 809) were woven with equivalent singles filament yarn and/or equivalent singles textured filling yarn (Tables 2a and 2b).

The test data on these fabrics show no significant change in fabric weight, breaking strength, permeability and Mullen Burst. However, an appreciable increase, as much as threefold, was observed in flexfold endurance with singles yarn. This can be explained in part by improved finish penetration into the singles fiber bundle, thus increasing filament lubricity and resistance to filament-to-filament abrasive degradation. However, this effect of finish penetration could be offset as the yarn diameter increases, as shown by only a slight increase in flexfold endurance of the ETDE 18 1/0 vs. ETDE 75 2/2 in Table 2b.

Table 2a. SINGLES YARN VS. PLIED YARN - STYLE 823

Fabric Number	Finish	Count	Warp	Filling	Weave	Weight	Breaking Strength	Porosity	Mullen Burst	MIT Flexfold
823	UM 716	54x30	ECDE 150 1/2	ETDE 75 1/2	3x1 Twill	9.6	305x140	62.6	357	7230x698
9123	UM 716	54x30	ECDE 75 1/0	ETDE 75 1/2	3x1 Twill	9.6	298x158	62.0	383	-- x968
9127	UM 716	54x30	ECDE 75 1/0	ETDE 37 1/0	3x1 Twill	9.5	284x140	60.3	334	24228x2039

Table 2b. SINGLES YARN VS. PLIED YARN - STYLE 809

Fabric Number	Finish	Count	Warp	Filling	Weave	Weight	Breaking Strength	Porosity	Mullen Burst	MIT Flexfold
809	UM 716	48x22	ECDE 150 2/2	ETDE 75 2/2	2x2 Br. Twill	15.9	471x190	58.3	556	10185x1520
9137	UM 716	48x22	ECDE 37 1/0	ETDE 75 2/2	2x2 Br. Twill	16.0	374x199	64.5	541	30543x1350
--	UM 716	48x22	ECDE 37 1/0	ETDE 18 1/0	2x2 Br. Twill	----	---	----	---	--- x1832

Combination Yarn (Filament Core Textured Yarn)

Although textured yarns usually begin with plied continuous filament yarn, availability of textured singles yarn makes it possible to ply continuous filament strands with textured strands, thus producing a

Since fiber glass fabrics containing filament yarn in the warp direction and textured yarn in the filling direction have received the most interest in the power industry, we concentrated on this type of fabric for this study.

In addition to fabric construction, the finish applied to the fabric is an improtant variable; hence the type and quantity of finish applied to the fabric have been included as a study variable.

Test Methods

Fabric properties related to fabric performance as a filtration media include weight, breaking strength, permeability, Mullen Burst and flexfold endurance. It must be pointed out, however, that no single fabric property or combination of properties can be used as a true guide to its performance in an actual baghouse, since other environmental factors enter into the picture. This has been illustrated by actual experience in several baghouses during recent years.

Fabric Weight-

Fabric weight is determined in accordance with ASTM D1910, using a die-cut specimen 6.75 inch x 6.75 inch whose weight in grams is equivalent to its weight in ounces per square yard.

Breaking Strength-

The breaking strength of a fabric in pounds per inch of width is determined according to Owens-Corning Fiberglas Corp. Test Procedure DF-509 using a Scott Tester. Results are reported as average warp values x average filling values.

Permeability-

Fabric permeability was measured with a Frazier Model 163A air permeability instrument at 70°F and 65% relative humidity at 0.5 inch water pressure differential across the fabric.

Mullen Burst-

Mullen Burst was determined on a B.F. Perkins Co. Model A tester with a D/I diaphram in accordance with Method 5122 of Federal Test Method Standard CCC-T-191b.

Flexfold Endurance-

Flexfold endurance was determined in accordance with ASTM D2176, using an MIT flexfold instrument. The specimen is held under tension with a four pound weight.

Fabric Count

The fabric count is the number of warp yarns (ends) per inch of fabric in the lengthwise direction and the number of filling yarns (picks) per inch in the crosswise direction. Fabric weight is directly proportional to the number of ends and picks. To a degree, breaking strength and Mullen Burst also increase as fabric count increases, but not always in direct proportion. On the other hand, permeability is directly proportional to the fabric count. Increasing the pick count of a fabric (Table 1) from 26 to 32 results in increased yarn density which inhibits air flow through the fabric, hence reducing permeability.

Table 1. FILLING YARN COUNT VS. FABRIC PROPERTIES

Fabric Number	Finish	Count	Warp	Filling	Weave	Weight	Breaking Strength	Porosity	Mullen Burst	MIT Flexfold
9126	UM 716	54x32	ECDE 75 1/0	ETDE 37 1/0	3x1 Twill	9.7	---	44.0	367	---
9127	UM 716	54x30	ECDE 75 1/0	ETDE 37 1/0	3x1 Twill	9.5	284x140	60.3	334	24228x2039
9128	UM 716	54x28	ECDE 75 1/0	ETDE 37 1/0	3x1 Twill	9.1	---	65.6	304	---
9129	UM 716	54x26	ECDE 75 1/0	ETDE 37 1/0	3x1 Twill	8.7	---	80.0	303	---

Yarn Construction

The simplest form of continuous filament yarn is the strand as it comes from the bushing through which molten glass is extruded. This is referred to as a "singles" yarn containing an organic sizing for improved strand integrity. Additional integrity is introduced by twisting the yarn slightly, usually less than one turn per inch.

In the early days of weaving fiber glass yarns, these singles yarns could not be effectively and efficiently utilized in weaving. Therefore, the fiber glass textile industry developed by weaving plied yarns, that is, finer strands twisted together to the desired construction. These plied yarns usually contained 3.8-4.4 turns per inch which imparted sufficient yarn integrity for weaving. This plying operation, on the other hand, required the use of more expensive input strands and the additional cost of the plying operation.

Singles yarn technology has progressed to where they can be efficiently woven, resulting in economic advantages over commercially standard plied yarn fabrics heretofore used in the filtration industry.

Similarly, early fiber glass yarn technology dictated the use of plied continuous filament yarn as the input raw material for the preparation of textured yarn. The texturizing process consists of passing yarn through a pressurized air jet under negative tension, i.e. overfeed. The air causes individual filaments to separate and fluff up, giving a textured yarn with the best properties of both input strands.

Test data on fabrics containing one or more strands of continuous filament yarn plied with two or more strands of textured yarn in the filling of two standard fabric constructions are given in Table 3. As would be expected, fabric weight, warp breaking strength and warp flexfold are unchanged.

But the continuous filament yarn acting as a core in the textured filling yarn increases the breaking strength and the flexfold in that direction, and contributes to an overall increase in Mullen Burst. The greater the ratio of filament-to-texturized strands, the greater the increase.

Table 3. FILAMENT CORE TEXTURED FILLING YARN VS. FABRIC PROPERTIES

Fabric Number	Finish	Count	Warp	Filling	Weave	Weight	Breaking Strength	Porosity	Mullen Burst	MIT Flexfold
830	UM 716	48x26	ECDE 37 1/0	ETDE 75 2/2	3x1 Twill	14.5	477x168	62.3	436	19000x1680
9043	UM 716	48x26	ECDE 37 1/0	(Note 1)	3x1 Twill	14.5	432x214	28.4	563	17100x9900
809	UM 716	48x22	ECDE 150 2/2	ETDE 75 2/2	2x2 Br. Twill	15.9	471x190	58.3	556	10185x1520
9045	UM 716	48x22	ECDE 150 2/2	(Note 2)	2x2 Br. Twill	15.3	431x270	52.6	708	--- x6236
9046	UM 716	48x22	ECDE 150 2/2	(Note 3)	2x2 Br. Twill	15.4	372x347	61.3	801	10220x6844

Note 1 - One end ECDE 75 1/0 plied with two ends ETDE 75 1/0.
Note 2 - One end ECDE 75 1/0 plied with three ends ETDE 75 1/0.
Note 3 - Two ends ECDE 75 1/0 plied with two ends ETDE 75 1/0.

The effect on permeability is another matter, as the data shows no definitive trends. The inclusion of one continuous filament strand in either a 3-ply or a 4-ply textured yarn results in lower permeability. However, when two plies of continuous filament yarn are combined with two plies of textured yarn, pemeability returns to the level of the all-textured yarn (fabric no. 9046 vs. fabric no. 809).

Since interest in the filament core textured filling yarn fabrics exists in upcoming baghouse installations, fabric properties of Style 830 and its derivatives with Teflon* B finish are given in Table 3a. Here again, the increase in breaking strength, Mullen Burst and flexfold endurance as a function of the filament core textured yarn is illustrated, being proportional to the pick count of the fabric as seen by comparing fabrics 9043, 9042 and 9041.

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* Trademark of E.I. duPont de Nemours & Co. Inc.

Table 3a. FILAMENT CORE TEXTURED FILLING YARN VS. FABRIC PROPERTIES

Fabric Number	Finish	Count	Warp	Filling	Weave	Weight	Breaking Strength	Porosity	Mullen Burst	MIT Flexfold
830	UM 714	48x26	ECDE 37 1/0	ETDE 75 1/3	3x1 Twill	15.4	698x247	46.0	468	8690x 500
9043	UM 714	48x26	ECDE 37 1/0	(Note 1)	3x1 Twill	14.9	792x347	32.1	603	6890x1430
9042	UM 714	48x24	ECDE 37 1/0	(Note 1)	3x1 Twill	14.5	764x328	36.7	594	-- --
9041	UM 714	48x22	ECDE 37 1/0	(Note 1)	3x1 Twill	14.0	770x317	40.6	529	-- --

Note 1 - One end ECDE 75 1/0 plied with two ends ETDE 75 1/0.

As shown in Table 3a, the combination filling yarn also lowers fabric permeability with Teflon B finish, hence being a yarn function rather than a finish function. Also, as previously illustrated, permeability increases as pick count decreases.

Weave Pattern

As a general rule, the less frequent the number of yarn interlacings, the higher the fabric permeability. Most filter fabrics are woven on four harnesses for stability in bag fabrication. Of the more common weave patterns, fabric permeability is lowest with the 2x2 broken twill weave, followed by crowfoot satin weave and 3x1 straight twill weave with the highest pemeability.

The effect of these and other weave patterns on fabric permeability is listed in Table 4. Fabric weight, breaking strength, Mullen Burst and flexfold endurance are not appreciably influenced by weave pattern for a given fabric count and yarn content.

Table 4. WEAVE PATTERN VS. FABRIC PERMEABILITY

Weave Pattern	Harness	Porosity
2x2 Broken Twill	4	50
3x1 Crowfoot	4	55
3x1 Straight Twill	4	67
2x2 Basket	4	69
1x5 Crowfoot	6	99
2x6 Crowfoot	8	113
Satin	8	124

Common Warp

Should the filtration industry make the transition from plied yarn fabrics to singles yarn fabrics (especially in the warp) as other industries using fiber glass fabrics have done, most of the fabrics can be woven on basically two warps, namely a 54-end warp of ECDE 75 1/0 and a 48-end warp of ECDE 37 1/0.

It is conceivable, however, that an entire range of filter fabrics could be woven on a single warp, thus leading to greater versatility by the weaver in supplying this full range of fabrics with reduced lead times and improved manufacturing flexibility.

To illustrate the concept, fabrics that could be woven on a 48-end ECDE 37 1/0 warp (Style 830 and Style 809) were redesigned for adaption to a 54-end ECDE 75 1/0 warp (fabric no. 9130 and fabric no. 9135). These fabrics and their properties, along with their precursors and properties, are given in Table 5. Since the 54-end warp of ECDE 75 1/0 yarn has about 40% less glass content than the 48-end warp of ECDE 37 1/0 yarn, the warp breaking strength would be expected to be reduced proportionally, which appears to be substantiated by the test data. Thus, Style 830 could be replaced by a fabric woven on a 54-end ECDE 75 1/0 warp without much compromise in fabric properties or performance. In addition, the heavier 16-ounce Style 809 could be replaced by a lighter 12-ounce fabric woven on the 54-end ECDE 75 1/0 warp with small compromise in warp breaking strength and Mullen Burst properties. As an alternative, a heavier filling yarn such as ETDE 37 1/3 could offset some of the property reduction.

Table 5. COMMON WARP

Fabric Number	Finish	Count	Warp	Filling	Weave	Weight	Breaking Strength	Porosity	Mullen Burst	MIT Flexfold
830	UM 716	48x2[illegible]	ECDE 37 1/0	ETDE 75 1/3	3x1 Twill	14.5	477x169	62.3	436	19000x1680
9130	UM 716	54x25	ECDE 75 1/0	ETDE 37 1/2	2x2 Br. Twill	12.9	280x208	56.6	399	16552x1430
9135	UM 716	54x20	ECDE 75 1/0	ETDE 18 1/0	2x2 Br. Twill	11.2	292x202	43.6	426	12934x1832
809	UM 716	48x22	ECDE 150 2/2	ETDE 75 2/2	2x2 Br. Twill	15.9	471x190	58.3	556	10185x1520

In addition, the common warp concept allows greater flexibility in fabric design to achieve desired fabric properties.

Fabric Finish

Historically, finishes for fiber glass filtration fabrics have been lubricants with thermal stability up to 500°F (260°C). Silicone oils, fluorinated hydrocarbons, graphite or combinations of these are typical of commercial finishes available during the past twenty years. Whereas the finish contributes to the life of the fabric under operating environments, new themally resistant chemicals and formulations are being developed, evaluated and made commercially available as proprietary finishes. To illustrate the effect of finish on fabric properties, test data was generated on a silicone-graphite finish (UM 708), Teflon B (UM 714) and a proprietary finish (UM 716). This data is presented in Table 6.

UM 708-

The UM 708 finish, a silicone-graphite finish typical of finishes commercially available over the past twenty years, does not appear to improve fabric performance of singles over plied yarns filament warp/textured filling fabrics as much as other finishes. Increasing the quantity of finish on the fabric increases flexfold, but has little influence on other fabric properties.

UM 714-

This Teflon B finish has been commercially available during the past few years and has proven successful in some power industry baghouses. This finish applied to singles warp/singles textured filling fabric (no. 9127) shows a significant improvement in flexfold characteristics over plied yarn fabrics (no. 823), with all other properties being equivalent (Table 2a). It is anticipated that this improvement in flexfold will lengthen the life of a filter bag under normal operating conditions.

The application of 7% Teflon B and 10% Teflon B to plied yarn fabric does not show any appreciable difference in fabric properties; on the other hand, when these two finish levels are applied to singles yarn fabrics, a dramatic difference in flexfold characteristics were observed, with the 10% loading showing better performance (Table 6).

Continuous exposure of Teflon B finished fabric to 500°F (260°C) shows severe degradation as illustrated by the low flexfold values, especially in the filling direction.

UM 716-

The UM 716 finish, a development of Uniglass Industries, is designed to contribute to prolonged bag life at operating temperatures as well as upon initial installation. It was shown earlier in this paper that the UM 716 finish on singles yarn fabric gave significantly improved fabric properties over plied yarn fabric (Table 2a and Table 2b). With prolonged exposure to elevated temperature (72 hr. at 260°C), flexfold endurance actually improved compared to other finishes which tend to deteriorate.

Table 6. FINISH TYPE AND CONTENT VS. FABRIC PROPERTIES

	823-UM 708		823-UM 714		823-UM 716	
	Cond. A	E72/260	Cond. A	E72/260	Cond. A	E72/260
Finish Content	2.2	---	7.5	---	4.8	---
Permeability	60.5	---	49.0	---	62.6	---
Mullen Burst	347	247	522	227	357	213
Strength - Warp	294	140	297	139	305	131
- Filling	157	134	150	99	140	93
Flexfold - Warp	3990	---	3759	---	7230	---
- Filling	128	39	290	82	698	---

	823-UM 708		823-UM 714	
	Cond. A	E72/260	Cond. A	E72/260
Finish Content	3.0	---	10.0	---
Permeability	62.4	---	53.4	---
Mullen Burst	332	272	466	237
Strength - Warp	256	212	332	159
- Filling	113	104	210	103
Flexfold - Warp	8734	---	---	2856
- Filling	90	---	---	22

	9127-UM 708		9127-UM 714		9127-UM 716	
	Cond. A	E72/260	Cond. A	E72/260	Cond. A	E72/260
Finish Content	1.7	---	9.9	---	4.0	---
Permeability	53.0	---	54.8	---	60.3	---
Mullen Burst	344	297	478	269	334	448
Strength - Warp	293	237	315	211	284	202
- Filling	130	101	153	99	140	110
Flexfold - Warp	4802	---	---	27779	24228	---
- Filling	223	---	---	540	2039	---

Summary

In the investigation of fabric variables on fabric performance as high temperature filtration media, a high degree of flexibility in fabric design is available based on raw material (yarn) availability with existing yarn technology combined with varying fabric counts and weave patterns, particularly if the number of warps are limited.

Fabrics woven with singles yarn rather than conventional plied yarn show distinct economic and performance advantages. This coupled with a high performance finish such as UM 716 could lead to overall fabric performance improvements in a baghouse, including the possibility of extended bag life.

Errata

1. Table 2a. Filling yarn in Style 823 is ETDE 150 2/2.
2. Table 3. Filling yarn in Style 830 is ETDE 75 1/3.

VERIFICATION OF PROJECTED FILTER SYSTEM DESIGN AND OPERATION

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ABSTRACT

A mathematical model is described for use by control personnel to determine the adequacy of proposed filter systems designed to minimize coal fly ash emissions. The model is structured so that by entering selected combustion, operating, and design parameters indicated by power plant and/or manufacturing personnel in computer format, the program user can forecast the expected particulate emissions and filter pressure loss. The model takes into account the concentration and specific resistance properties of the dust, air/cloth ratio, sequential compartmentized operation and the method, intensity and frequency of cleaning. The model function depends upon the unique fabric cleaning and dust penetration properties observed with several coal fly ashes (including lignite) and woven glass fabrics. Prior validation of a precursor model showed excellent agreement with measured field performance for the Sunbury, Pennsylvania and Nucla, Colorado fabric filter systems.

INTRODUCTION

Basis for Verification Model Design

GCA/Technology Division, under contract with the U.S. Environmental Protection Agency,* has developed a mathematical model to describe the performance of woven glass fabric filters used for the collection of coal fly ash.[1-4] In its original format, certain supporting calculations and estimating processes were performed outside the computer program to provide more latitude in model validation experiments. The original format, however, does not satisfy the needs of pollution control personnel who are often required to determine whether an existing or proposed filtration system will meet current particulate emission standards. Aside from requiring decisions best relegated to the filtration expert, the original model also provided more

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*Contract No. 68-02-1438, Task Order No. 5, Program Element No. EHE624.

information on filter system performance than necessary to support enforcement personnel in their field evaluations.

What is required by pollution control personnel involved in enforcement activities is a relatively uncomplicated procedure whereby they can input specific values for the controlling filtration and process parameters into a predictive model and receive as output a summary of the probable system performance. For present purposes, the model should apply to fly ash removal from coal-fired boiler effluents where woven glass fabrics constitute the dust collection medium and where the average and range in outlet particulate concentrations are the primary concern. The model output should, however, indicate whether the predicted ranges in fabric pressure loss and the frequency of fabric cleaning conform approximately to system design specifications. For example, if the proposed operating plans called for intermittent cleaning; e.g., every 2 hours, whereas the model indicates that continuous cleaning may be required, an increase in operating pressure loss and a shortening in fabric service life might be inferred. Both the control agency and the equipment user are thus alerted to potential problems such that corrections may be considered before, rather than after the fact.

Application of Verification Model

The modified form of the original model discussed in this paper can be used by enforcement personnel without extensive training in filtration technology. Although the indicated modifications are intended to provide both diagnostic and design capabilities, it is expected that the former application will see the greatest use.

If it is desired to ascertain whether a filter system scheduled for construction or just about ready to go on-line will meet local, state or federal emission standards, the engineer making this assessment will use the operating, fabric and dust parameters provided by the user and/or the collector manufacturer. Unless the model indicates that the filter system will not satisfy the emission requirements within certain boundaries, time constraints will probably not allow enforcement personnel to determine whether, in fact, the cleaning system is providing optimum performance. The latter effort, however, might be profitably undertaken by the user or manufacturer along with the adoption of any corrective measures needed to bring the system into compliance.

BASIS FOR EXPERIMENTAL MODEL DESIGN

The developmental aspects for the filtration model have been discussed in several recent publications.[1-4] In this paper, it suffices to point out that the model embraces several well recognized filtration principles that have been reviewed extensively by Billings and Wilder.[5] The drag curve in Figure 1 and Equations (1a), (1b) and (5) through (9) in Table 1 typify some of the fundamental relationships used in the model design.

The introduction of three new concepts, however, has made it possible to estimate the performance of a multicompartment filter system in much more realistic fashion than previously possible.

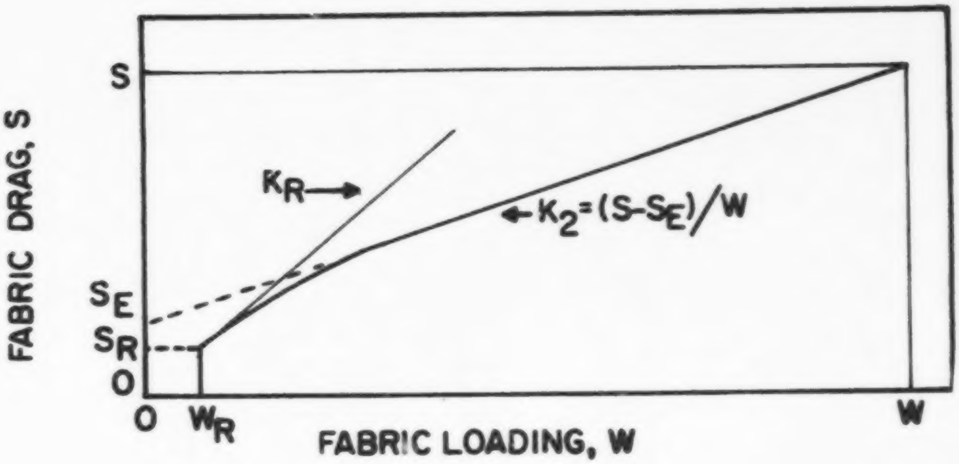
S
FABRIC DRAG, S
K_R
$K_2 = (S-S_E)/W$
S_E
S_R
O
O
W_R
W
FABRIC LOADING, W

Figure 1. Linear and curvilinear drag versus fabric loading curves

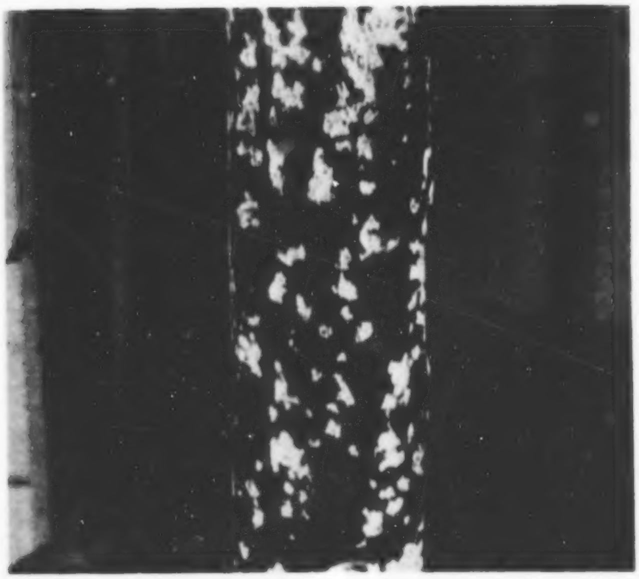

Figure 2. Cleaned (bright) and uncleaned (dark) areas of glass bag with partial fly ash removal. Inside illumination with fluorescent tube

Table 1. SUMMARY OF MATHEMATICAL RELATIONSHIPS USED TO MODEL FABRIC FILTER PERFORMANCE

Equation number	Equation	Comments	Terms and units
(1a) (1b)	$S = P/V = S_E + K_2 W$ $P_L = S_E V + K_2 V (W_p - W_R)$	Equations (1a) and (1b), which are used for the linear model, relate filter drag, S, or pressure loss, P, to fabric loading, W. P_L is the limiting pressure loss and W_P the corresponding fabric loading. Cleaning initiated at P_L. S_E is the effective residual drag, W_R the residual fabric loading for the cleaned areas, K_2 the dust specific resistance coefficient and V the face velocity.	$P,\ P_L = N/m^2$ $S,\ S_E = \frac{N\text{-min}}{m^3}$ $V = m/min$ $W,\ W_R = g/m^2$ $K_2 = \frac{N\text{-min}}{g\text{-m}}$ See Figure 1.
(2) (3)	$S = S_R + K_2 W' + (K_R - K_2) W^*\left(1-\exp(-W'/W^*)\right)$ $W' = W - W_R$ $W^* = (S_E - S_R + K_2 W_R)/K_R - K_2$	Equations (2) and (3), which are used for nonlinear model, describe initial curvature often seen in S versus W curves and also the later approach to linearity. K_R is the initial slope for curvilinear region, S_R the actual residual drag for cleaned area, and W^* a system constant. If W^* is zero, program automatically uses linear model.	$K_R = \frac{N\text{-m}}{g\text{-m}}$ $S_R = \frac{N\text{-min}}{m^3}$ $W^* = g/m^2$ See Figure 2.
(4)	$S = P/V = \left(\sum_{i=1}^{n} \frac{a_c}{S_c} + \frac{a_{u_1}}{S_{u_1}} + \ldots \frac{a_{u_i}}{S_{u_i}}\right)^{-1} A$	Equation (4) describes resultant drag for parallel flow through cleaned and uncleaned regions of fabric surface. The term a_c denotes cleaned fraction of fabric surface with its initial cleaned drag, S_c. "A" refers to total surface fraction and "n" to the total number of fabric elements. Subscript "u" refers to all areas not "just cleaned."	a_c = dimensionless $S_c,\ S_u = \frac{N\text{-min}}{m^3}$ A = dimensionless = 1.0 See Figures 1 and 2.
(5)	$K_2 = 1.8\ V^{.5}$	Equation (5) describes effect of face velocity on K_2 with coal fly ash, (MMD = 9 µm and σ_g = 3) and at temperature T = 24°C.	MMD = cm^{-1} σ_g = dimensionless T = °C
(6)	$(K_2)_f = (K_2)_m \left[(S_o)_m / (S_o)_f\right]^2$	Equation (6) defines K_2 for filtration conditions (f) when the K_2 value is available for the same dust but with different measured (m) specific surface properties, S_o.	$S_{o_f},\ S_{o_m} = cm^{-1}$
(7)	$K_2 = \frac{\mu S_o^2}{6 \rho_p C_c}\left[\frac{3 + 2(\beta)^{5/3}}{3-4.5(\beta)^{1/3} + 4.5(\beta)^{5/3} - 3(\beta)^2}\right]$	Equation (7) predicts K_2 in terms of gas viscosity, µ, specific surface parameter, S_o, cake bulk density, $\bar{\rho}$, and discrete particle density, ρ_p. Equation (7) used only when no direct K_2 measurements are available. The Cunningham correction, C_c, approaches one for large (fly ash) particles.	µ = poise $\bar{\rho}_p,\ \rho_p = g/cm^3$ ε = dimensionless C_c = dimensionless
(8)	$1 - \bar{\rho}_p/\rho_p = \varepsilon\ ;\ \bar{\rho}/\rho_p = \beta$		

Table 1 (continued). SUMMARY OF MATHEMATICAL RELATIONSHIPS USED TO MODEL FABRIC FILTER PERFORMANCE

Equation number	Equation	Comments	Terms and units
(9)	$S_o = 6\left(\frac{10^{1.151 \log^2 \sigma_g}}{MMD}\right)$	Equation (9) computes distribution specific surface parameter, S_o, from cascade impactor data for a logarithmic normal mass distribution.	$S_o = cm^{-1}$
(10)	$W_p' = \frac{P_L - S_E V}{K_2 V} + W_R + \frac{C_i V \Sigma t}{2}$	Intermittent, pressure controlled cleaning system. Substitution of W_p' from Equation (10) in Equation (11) gives area fraction cleaned, a_c, as function of limiting pressure loss, P_L, and previously cited system parameters. W_p' accounts for the fact that the average W_p value over the cleaning cycle will exceed the initial values.	a_c = dimensionless
(11)	$a_c = 1.51 \times 10^{-8} W_p'^{\,2.52}$		
(12)	$a_c = (6.00 \times 10^{-3}) (V C_i t_c)^{0.715}$ $t_c = \Sigma t + t_f$	Intermittent, time controlled cleaning. Equation (12) applies when total cycle time, t_c is given. Note that t_c is the sum of time required to clean all compartments, Σt, plus the time between compartment cleaning, t_f. Face velocity, V, and inlet concentration C_i must be nearly constant for safe use of time control.	t_c, Σt, t_f = min $C_i = g/m^3$ V = m/min
(13)	$W_p = 166.4 (C_i V \Sigma t)^{0.284}$	Continuously cleaned system. Equation (13), which shows dust loading on compartment ready for cleaning, applies when $W_p \gtrapprox 10$ times W_R. Equation (14) computes a_c for a continuously cleaned system.	m = number of compartments
(14)	$a_c = (6.00 \times 10^{-3}) (V C_i \Sigma t)^{0.715}$		
(15)	$C_o = \left[Pn_s + (0.1 - Pn_s) e^{-aW}\right] C_i + C_R$	Equations (15) through (17) are empirical relationships used to compute outlet concentrations, C_o, in terms of incremental increase in fabric loading ($W' = W - W_R$); inlet dust concentration C_i; and local face velocity, V. The term C_R is a constant, low level outlet concentration that is characteristic of the dust fabric combination. Pn_s and a are curve fitting constants for specific systems.	C_i, C_o, $C_R = g/m^3$ $W' = g/m^2$ V = m/min Pn_s, Pn_t = dimensionless $a = m^2/g$
(16)	$Pn_s = 1.5 \times 10^{-7} \exp\left[12.7 (1 - e^{-1.03V})\right]$		
(17)	$a = 3.6 \times 10^{-3} V^{-4} + 0.094$		
(18)	$Pn_t = \frac{1}{V_t IJ} \sum_{i=1}^{I} \sum_{j=1}^{J} Pn_{ij_t} V_{ij_t}$	Equation (18) depicts basic iterative structure for defining system penetration at any time, Pn_t as a function of parallel flow through "I" compartments (each subdivided into "J" individual areas) where local face velocities and fabric loadings are variable with respect to time and location.	I = No. compartments J = No. areas per compartment t = time

The first describes dust separation from woven fabrics as a flaking-off process wherein the application of cleaning energy causes dust separation to occur at the dust layer-fabric interface. The result is that the first cleaning of a uniformly loaded fabric produces two characteristic regions, the bright, cleaned areas shown in Figure 2 and the adjacent, uncleaned areas from which no dust is dislodged.[2] Because there exist characteristic values for residual drag, S_R, and residual loading, W_R, for the cleaned regions and because the drag and loading for any uncleaned region are also definable, it becomes possible to compute the resultant fabric drag for the overall filter system as shown in Equation (4), Table 1.

The second concept is based upon a straightforward description of the fabric cleaning process[1-3-4] that relates the amount of dust removed to the method of cleaning and the prior dust loading on the fabric surface. Although both collapse with reverse flow and mechanical shaking have been quantitated, only the collapse and reverse flow process is considered in the present model for fly ash filtration with woven glass fabric. This decision is based on the fact that the very brief and low-intensity, supplemental shaking used in some field units does not appear to play a significant role in dust cake removal. Equations (10) through (14), Table 1, depict the types of calculations carried out within the program that are used to estimate the fraction of cleaned fabric area, a_c, exposed as a result of the cleaning regimen and the fabric loading immediately before initiation of cleaning.

The third concept evolves from the unique penetration behavior exhibited by fabrics woven from multifilament and bulked yarns. A temporary or permanently unblocked pore presence (often referred to as pinholes) may contribute to extensive penetration of the upstream aerosol. Furthermore, only minor differences may be detected between the inlet and outlet dust size properties and the potential for extremely high collection by the undisturbed dust cake is never realized[1] because of gas flow diversion through the pores. Equations (15) through (18), Table 1, take into account the variable nature of the dust penetration through the filter medium from the time that it is cleaned until a substantial dust deposit has accumulated. The term C_R depicts a characteristic, lower limit in effluent concentration (for fly ash-glass fabric systems) that is approached asymptotically as filtration progresses between cleaning intervals.

ADAPTATION OF EXPERIMENTAL MODEL FOR FIELD USE

In order to encourage the use of the model in real field applications, the following changes were made. First, the data inputs to be provided by the model user have been regrouped into four major categories: Design, Operating, Dust and Fabric Properties, and Special Program Instructions, as discussed later. Secondly, all intermediate calculations are now performed within the program so that the main responsibility of the model user is to enter the required model inputs in their correct units and in the proper sequence. Third, the model user is given several alternate choices as to certain inputs so that he can make optimum use of the available data. In those isolated cases where required input data are not available or are incomplete, typical values are recommended for use. Specific reference is made here to the terms S_E and W_R which have been previously shown to vary within rather limited ranges for fly ash-glass fabric combinations and to average about 350 N-min/m^3 for S_E and 50 g/m^2 for W_R. Fourth, the model user is given the option of selecting the program output best suited to his individual needs. Although it is possible to choose a very detailed output, which entails a point-to-point data printout with respect to both time and location, the more practical output, except for experimental applications, is that which describes the overall changes in system performance with respect to time. In many cases, a presentation of average values alone may suffice along with the maximum expected levels for outlet concentration and/or overall filter resistance. Although not absolutely essential, a graphical display of the data outputs can also be provided, which enables the model user to better visualize the temporal changes in system performance.

APPRAISAL OF FILTER DESIGN

Review of Plans and Operating Specifications

The use of the modeling technique described here is directed to the appraisal of new filter systems for which the model functions mainly as a diagnostic tool. It is emphasized, however, that the model can also play an important role in the design of new systems and in filtration research. The summary description given in this paper is intended to highlight the model's capability to predict filter system performance based upon specified design and operating criteria.

In reviewing plans and operating specifications for proposed systems, the following guidelines may be available to aid enforcement personnel. First, the new system may replicate closely in physical design and operating conditions an on-line system for which performance data are available. Second, pilot scale field tests may have been performed for similar boiler designs and fuel properties where the filterability of fly ash has been established even though operating plant sizes may have differed. Third, the filter system supplier may have the reputation for selecting admittedly conservative operating parameters with the intent to "tune" the installed system on a trial-and-error basis to an operating regimen conforming to the required pressure loss and effluent concentration levels.

The probability of success with preliminary (or trial) parameters depends largely on the experience, intuition and conservatism of the vendor. Here, the application of reliable modeling techniques by the supplier and/or the enforcement engineer should improve the reliability of any estimates of probable system performance. At this juncture, it should be emphasized that if the enforcement group is the first to use the modeling approach (which for the moment will be assumed to be sufficiently reliable to justify acceptance or rejection of a system design) then the equipment supplier and/or user may be placed in the unfortunate position of having to make several costly drawing modifications or purchase order changes. Therefore, it would appear reasonable that fabric filter manufacturers adopt in their design efforts the same modeling procedures that enforcement personnel will use in their assessment of the system capability.

Combustion System Parameters Versus Filter Design

Although the physical operation of the model requires no arguments to defend the selected data inputs, its optimum application is strongly dependent upon a basic understanding of the process to be controlled by the filter system. A summary of supporting data that may assist the model user in his decisionmaking is given in Table 2.

Although most items are self-explanatory, some additional comments are offered for certain factors that are often associated with system malfunctions or substandard performance. For example, failure to allow for possible increases in combustion rate (Item 1) or increased ash content in the coal (Item 4) will demand increased fabric cleaning (Item 7) if the system is to be operated within fixed pressure loss constraints. The result may be decreased bag life accompanied by higher particle emission rates because of possible bag damage and greater filtration velocities. An attempt to reduce both space requirements and collector and fabric costs by operating at higher air-to-cloth ratio (Item 6) poses the risk of increased dust penetration and reduces the margin in collector capacity to accommodate to load levels or dust concentrations higher than expected in the original design.

Guideline Sensitivity Tests

In addition to the model per se, guideline tables and graphs have been prepared whose main role is to alert the model user as to the relative importance of the system variables. For example, given the possibility that the ash content of the coal (and flue gas) may vary appreciably both in concentration and size, the overall impact on system pressure loss, frequency of cleaning and effluent properties must be determined.

A summary sampling of sensitivity tests showing the interrelationships among the more important variables involved in the filter system operation are indicated in Table 3. For example, the first two data groupings (1 and 2) indicate how average pressure drop, penetration and time between cleaning might vary due to differences or errors in estimating the fractional area cleaned, a_c, for two different systems. As a result of variations in velocity and cleaning frequency, the test range for a_c (0.1 to 1.0) has a decidely different impact on both average pressure drop and penetration.

Further reference to the tabulated data confirms the observation that the absolute effect of changing one variable depends strongly upon the magnitude of the other system variables. In some cases, one might conclude that variations in any one data input have little effect on system performance based upon resistance and emission criteria. However, when the time between cleaning increases from 6.6 to 672 minutes for a test velocity range of 0.3 to 0.91 m/min, data group 6, the frequency of fabric cleaning is increased nearly 20 times. Figure 3 shows the effect of variations in face velocity, V, and limiting pressure, P_L, on the average system pressure loss, $\bar{P}$, when all other system variables are held constant. The lowest pressure curve describes the resistance path for a continuously cleaned system. Once an average velocity is selected, the average resistance can never be lower than that corresponding

Table 2. SUPPORTING DATA FOR EVALUATION OF COMBUSTION AND FILTRATION PROCESSES

Operational or design factor	Expected effects	Special precautions and/or problems
1. Base load or peaking boiler	Variability in flue gas volume, temperature and dust concentration and composition.	Size filter for maximum flow-size compartment and duct heating equipment for minimum flow. Note possible changes in dust properties with flow rate.
2. New system or retrofit	Higher costs with retrofit, deviations from good design because of limited space.	Possible flow distribution and duct or manifold dust settlement problems. Excess dust penetration in high gas flow regions.
3. Fan capacity and response to variable static load	Cleaning frequency varies with fan static capability. Possible variation in gas handling capacity with large changes in filter pressure loss.	Frequent cleaning needed for low bag pressure loss can decrease bag life. Overresponse of draft fans to static pressure changes can cause load level variations
4. Type of coal	Size and composition of uncontrolled effluent depends on ash and sulfur content of fuel.	Design for maximum ash content. Be alert for changes in size properties or H_2SO_4 condensation with high sulfur coals.
5. Design resistance (pressure loss) across fabric filter	Fan power requirements increase with filter pressure loss. High design resistance allows more flexibility in dust concentrations and air-to-cloth ratio.	Design pressure loss limit should be based on highest possible fabric loadings and/or flue gas flow rate.
6. Design air-to-cloth ratio (face velocity)	The higher the face velocity the less fabric area (and cost) required. Conversely, resistance and fan power needs are greater.	High velocity operation requires base load operation with constant ash content. Penetration will be higher although usually not excessive.
7. Cleaning frequency and intensity	Filter pressure loss and fan power vary inversely with frequency and intensity of cleaning. Excursions from mean operating resistance are minimized.	Fabric wear increases with rate and intensity of cleaning. Particulate emissions may be higher due to overcleaning.
8. Materials of construction, damper design, pressure and temperature sensing, and fabric cleaning controls	Good construction and instrumentation practice precludes panel warping, gasket failures, corrosion and condensation in baghouse.	Leakage of cold air into baghouse with condensation and bag plugging. Cooling due to insufficient insulation. Rusting and jamming of compartment dampers. Failure to initiate cleaning at specified pressure level or to activate supplementary heaters.
9. Maintenance and safety features Standby compartment Bypass capability Alarm systems	Standby compartment permits safer and more rapid inspection and maintenance. Bypass capability prevents irreversible damage to fabrics and allows for safe boiler turn down. Excessive pressure drop alarms may prevent bag rupture.	Proper maintenance avoids equipment breakdown. Lack of alarm systems may cause loss of several bags, and also lead to decreased excess air in combustion process.

Table 3. DATA SAMPLING FROM SENSITIVITY TESTS

Data group	Constant parameters[a]				Variable[a] parameter	Average pressure drop (N/m^2)	Average penetration (percent)	Time between cleanings (min)
1	$K_2 = 1.0$	$V = 1.22$	Continuous	$C_i = 6.87$	$a_c = 0.1$	4171	0.78	0.
					$a_c = 0.4$	1690	0.57	0.
					$a_c = 1.0$	1209	0.70	0.
2	$K_2 = 1.0$	$V = 0.61$	$P_L = 1000$	$C_i = 6.87$	$a_c = 0.1$	1130	0.13	8.0
					$a_c = 0.4$	860	0.13	80.0
					$a_c = 1.0$	713	0.14	170.
3	$K_2 = 1.0$	$V = 1.22$	Continuous	$a_c = 0.4$	$c_i = 2.29$	1159	0.78	0.
					$c_i = 6.87$	1690	0.57	0.
					$c_i = 22.9$	3517	0.77	0.
4	$K_2 = 1.0$	$V = 0.61$	$P_L = 1000$	$a_c = 0.4$	$c_i = 2.29$	810	0.029	270.
					$c_i = 6.87$	860	0.13	80.
					$c_i = 22.9$	1050	0.17	10.
5	$K_2 = 1.0$	$c_i = 6.87$	$a_c = 0.4$	Continuous	$V = 0.61$	560	0.36	0.
					$V = 0.8$	865	0.32	0.
					$V = 1.22$	1690	0.57	0.
6	$K_2 = 1.0$	$c_i = 6.87$	$a_c = 0.4$	$P_L = 1000$	$V = 0.3$	726	0.037	672.
					$V = 0.61$	860	0.13	80.
					$V = 0.91$	1097	0.30	6.6
7	$V = 0.61$	$P_L = 2000$	$C_i = 2.29$	$a_c = 0.4$	$K_2 = 1$	1445	0.08	759.
					$K_2 = 3$	1440	0.19	240.

[a] a_c = dimensionless, $C_i = g/m^3$, $P_L = N/m^2$, K_2 = N-min/g-m, V = m/min.

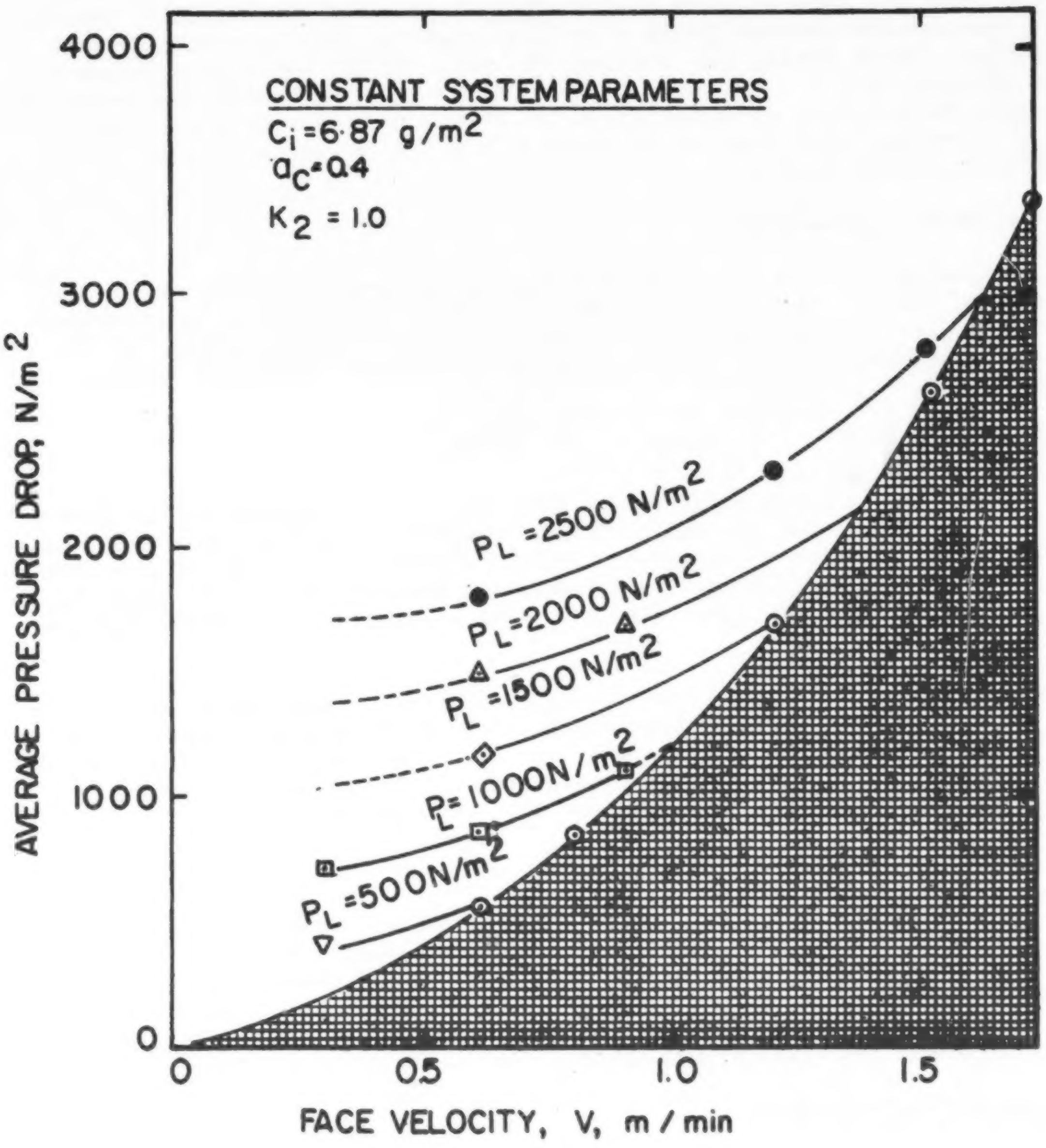

Figure 3. Effect of face velocity and limiting pressure drop on average pressure loss for a 10-compartment system, with a cleaning time of 30 minutes

to the velocity intercept with that curve; i.e., no pressure-velocity coordinate can exist in the shaded region. Thus, if one selects a limiting pressure loss of 1000 N/m^2 as the point where cleaning is to be initiated and concurrently selects a face velocity of 1.5 m/min, the system automatically reverts to a continuously cleaned system with an average operating pressure drop of 2500 N/m^2, far exceeding the limiting pressure. On the other hand, given a face velocity of 1.0 m/min and a limiting pressure of 2000 N/m^2, the velocity-pressure intersection occurring above the shaded zone indicates that the system will operate according to the selected V and P_L values and on an intermittently cleaned basis.

TYPICAL MODEL APPLICATION

Following a survey of relevant background information, enforcement personnel can then proceed to collate the data inputs specified in Table 4, convert each entry to the correct units and, finally, to list all items in the specified sequence so that they will be entered on the designated program cards.

Design Data

Generally, it is expected that either the user or supplier of the filtration system can provide the DESIGN DATA although the supplier would appear to be the better informed data source. Items 1 through 3 represent firm entries along with Item 6, the reverse flow velocity. However, the latter item, V_R, may be varied in the field by relatively simple means; e.g., control dampers, or fan sheave ratio.

If the vendor indicates both the expected time between compartment cleanings, Item 4, and the upper pressure loss limit at which the cleaning cycle is to be initiated, Item 5, the model user must input one or the other but not both, depending upon whether system resistance or frequency of cleaning is considered the overriding factor by the user or supplier.

Operating Data

The OPERATING DATA called out in Table 4, Items 7 through 10, derive from both combustion related parameters; i.e., total flue gas flow, gas temperature and inlet dust concentration and the face velocity (or air-to-cloth ratio) specified by the filter system supplier. The entry of Item 10 allows the program to correct inlet gas concentration to the correct value if the measured and compartment temperatures are not the same.

Dust and Fabric Properties

Although many important variables are tabulated within the DUST AND FABRIC PROPERTIES category, it is emphasized that only selected groupings, and never the entire listing, are entered in the program at any one time. For example, if K_2 for the fly ash or dust of interest, Item 11, has been determined by prior measurement, (which represents the most reliable approach), it is only

Table 4. DATA INPUTS PROVIDED BY MODEL USER

Item	Description	Units[a]	Card	Note
	Design Data			
0	Title	-	1	
1	Number of compartments, n	n	2	
-	Cleaning times	-	-	
2	• Single compartment, Δt	min	2	
3	• All compartments, full cycle, Σt	min	2	
4	Time between compartment cleaning, t_f	min	2	1
5	Limiting pressure, P_L	N/m^2	2	
6	Reverse flow velocity, V_R	m/min	2	
	Operating Data			
7	Average face velocity at filtration temperature, V	m/min	3	
8	Compartment gas temperature, T	°C	3	
9	Inlet dust concentration, C_i	g/m^3	3	
10	• Indicated measurement temperature	°C	3	
	Dust and Fabric Properties			
11	Specific resistance coefficient, K_2	n-min/g-m	4	2
12	• At indicated measurement temperature	°C	4	
13	• At indicated face velocity	m/min	4	
	Size Properties of Inlet Dust			
14a,b	• Mass median diameter, MMD	µm	4	3
15a,b	• Geometric standard deviation, σ_g	(dim)	4	
	Size Properties of Reference Dust			
16a	• Mass median diameter, MMD	µm	4	
17a	• Geometric standard deviation, σ_g	(dim)	4	
18b	Discrete particle density, ρ_p	g/cm^3	4	
19b	Dust cake bulk density, $\bar{\rho}$	g/cm^3	4	
20	Effective residual drag, S_E	$N\text{-}min/m^3$	5	4
21	• Indicated measurement temperature	°C	5	

Table 4. DATA INPUTS PROVIDED BY MODEL USER

Item	Description	Units[a]	Card	Note
22	Residual, cleaned, fabric loading, W_R	g/m^2	5	
23a	Residual, cleaned fabric drag, S_R	N-min/m^3	5	5
24a	• Indicated measurement temperature	$^{\circ}$C	5	
25a	Initial slope, K_R	N-min/g-m	5	
26a	• Indicated measurement temperature	$^{\circ}$C	5	
27a	System constant, W^*	g/m^2	5	
	Special Program Instructions			
28	Maximum number of cycles to be modelled, ~20	(dim)	6	6
29	Type of results desired	–	6	7
30	"X" axis plot length, inches	in.	6	
31	"Y" axis plot length, inches	in.	6	

[a] (dim) = dimensionless.

Notes:

1. Enter Item 4 or 5.
2. Item not required when Items 14b, 15b, 18b and 19b are entered.
3. Options "a" or "b" require that all "a" entries (14a, 15a, 16a, 17a) or all "b" entries (14b, 15b, 18b and 19b) be entered.
4. Enter Items 20, 21 and 22 only for linear drag model.
5. Enter Items 20 through 27a for nonlinear model.
6. Fewer cycles if printout shows convergence to steady state.
7. DETAILED/ - All data points, area by area plus average pressure loss, P, and penetration, Pn, plus point-by-point summary for all time increments.

   SUMMARY/ - Average pressure loss and penetration plus point-by-point summary for all time increments.

   AVERAGE/ - Average pressure loss and penetration only.

   PLOT/ - All data plotted in addition to any tabulation for DETAILED/ SUMMARY/, and AVERAGE/ data.

necessary that the temperature and velocity at the time of the K_2 measurement, Items 12 and 13, be entered.

If a K_2 value is available for the same dust to be filtered, but for a different set of size parameters than those associated with the filtration process, Items 11, 12 and 13 are entered as before along with the size parameters describing the dust to be filtered, Items 14a,b and 15a,b and the reference dust for which a size description is available, Items 16a and 17a. The program is designed to compute an estimate of K_2 from the above inputs which is considered to be less reliable than any direct measurement but superior to an estimate derived solely from theoretical considerations.

With no information on K_2 but having samples of the fly ash available from which bulk density and discrete particle density can be determined plus size distribution data obtained by prior cascade impactor sampling, the model will calculate K_2 based upon theoretical principles. The approach utilizes the basic Kozeny-Carman theory[5] with modifications and applications described by Happel[6] and Rudnick[7], respectively. When K_2 is developed in the above manner, the model user is required to enter only Items 12, 13, 14a,b, 15a,b, 18b and 19b. Unfortunately, comparative measurements have indicated that K_2 values calculated from Equation (7), Table 1, have at best a ± 50 percent accuracy.[1]

Two basic equations have been suggested for describing the relationship between filter drag, S, and fabric dust loading, W, Equations (1b) and (2), respectively, Table 1. The first describes the linear model from Figure 1 which is represented by the extrapolation of the linear section of the drag curve to the drag axis to form the intercept, S_E. The latter term is referred to as the effective residual drag. If there exist test data to construct the complete drag curve, including the temperature of measurement, Items 20 through 26a can be readily obtained by direct observations (S_R, W_R); graphical measurement of the slopes (K_R and K_2); and computation of W^* by means of Equation (3), Table 1.

When the linear model is chosen, it is necessary to enter only Items 20, 21 and 22 in the program with no inputs required for Items 23a through 27a. In selecting the linear approach, there is a possibility that performance parameters predicted by the model (mainly the emission characteristics) may be lower than the true value by too great an extent. Hence, despite the need for more data inputs, the use of the nonlinear model might represent the safer approach. In the latter case, Items 20 through 27a must be entered into the program.

Special Program Instructions

Unless indicated to the contrary, all Items shown in Table 4 are necessary inputs by the model user. Where no data input is required, the entry may be left blank or entered as a zero. The entries listed under Special Program Instructions enable the model user to obtain the program output in a format best suited to his immediate needs. Based upon several trial runs with the model, it appears that a steady state operating regimen is usually reached before the trial system has gone through 20 complete filtering and cleaning cycles, Item 28. In real time, this means the availability of a printed or graphical output display within roughly 15 to 20 minutes of the data insertion into the program.

The extent of the detail required, Item 29, can be selected in accordance with the codings, DETAILED, SUMMARY, AVERAGE and PLOT indicated in the Table 4 footnotes.

An inspection of the variables identified in Table 4 as data inputs, indicates that many of them do not appear in the basic modeling equations shown in Table 1. The major role of the former variables; e.g., $\bar{\rho}_p$, MMD, σ_g, T (and gas viscosity) is to permit the necessary calculations within the program for defining the primary variables appearing directly in the model such as K_2 or a_c.

EXAMPLES OF MODEL PERFORMANCE

Detailed descriptions of preliminary tests of the experimental fabric filtration model have been presented in previous reports.[1,3,4] The only difference in the earlier modeling was that certain claculations pertaining to estimates of a_c and K_2 were performed outside the model. The availability of field performance data plus key input parameters corresponding to those cited in Table 5 for Sunbury, Pennsylvania[8] and Nucla, Colorado[9] power plants provided a good opportunity for model validation. A comparison of predicted and measured values for average penetration and resistance characteristics for the above system is shown in Table 4. The results suggest that the model provides a good estimate of field performance, although it is recognized that more data are required to substantiate the reported level of agreement. Figure 4, in which traces from actual Nucla resistance charts are superimposed on the predicted resistance curve generated by the model, again suggests that the model is a good predictor of field performance when supplied the proper input data. Figure 4 is also representative of the type of plots that can be provided as a program option.

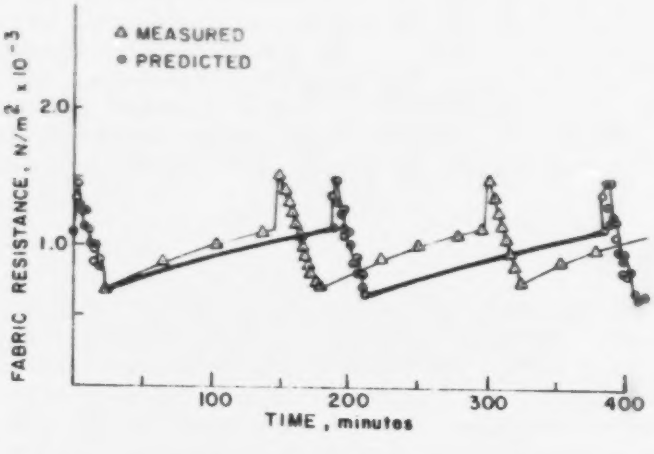

Figure 4. Nucla baghouse simulation, resistance versus time versus actual field measurements

Table 5. MEASURED AND PREDICTED PERFORMANCE FOR WOVEN GLASS BAGS WITH COAL FLY ASH

	Percent penetration	
	Measured[a]	Predicted[a]
Nucla, Colorado	0.21	0.19 (1.52)[b]
Sunbury, Pennsylvania	0.15	0.20
	Resistance-N/m^2	
	Measured	Predicted
Nucla, Colorado		
Average, cleaning and filtering	1030	972
During cleaning only	1700	1520
Maximum just before cleaning	1160	1160
Minimum just after cleaning	850	720
Sunbury, Pennsylvania		
Average, cleaning and filtering	635	620
During cleaning only	710	663
Maximum just before cleaning	710	663
Minimum just after cleaning	560	567

[a] Averaged over cleaning and filtering cycles.

[b] During cleaning cycle only.

ACKNOWLEDGMENTS

The authors express their appreciation to Dr. James H. Turner, EPA Project Officer, for his technical support throughout the program.

This project has been funded at least in part with Federal funds from the Environmental Protection Agency under contract number 68-02-1438, Task Order Nos. 5, 6 and 7, and contract number 68-02-2607, Task Order Nos. 7 and 8. The contents of this publication do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency, nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government.

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PRECIPITATORS? SCRUBBERS? OR BAGHOUSES? FOR SHAWNEE

(WHY TVA IS INSTALLING BAGHOUSES)

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On the 14th day of March, this year, TVA awarded a contract to Envirotech Corporation of Lebanon, Pennsylvania, for design, fabrication, and installation of structural baghouses for its ten-unit Shawnee Steam Plant near Paducah, Kentucky. I am told that this is the largest such installation ever undertaken in the baghouse or fabric filter industry. One engineer asked me, "Al, are you really going to install baghouses on all ten units? You are not going to try it on one or two units first?" That would be a logical way to approach a relatively new application, but we did not have that luxury since time would not permit. Our problem at Shawnee was of a very large magnitude due largely to the number of units--so our solution had to take on equal proportions. For many years at TVA, I have been involved in the design of "The Largest Steam Plant" or "The Largest Boiler or This or That" just because of the size of our utility and its rapid growth pattern. However, in this particular case, I am not the least bit interested in whether Shawnee is the largest baghouse installation ever undertaken. Perhaps it is, perhaps not; I am really not concerned. I am concerned with the ultimate magnitude of its success. I am interested in the quality and successful technical application of this installation, and that it proves capable of removing fly ash efficiently on a continuous basis for the remaining plant life.

Why would TVA depart from its past practice of installing electrostatic precipitators and select fabric filters for particulate control on such a large project? For the next few minutes, I hope to answer this question and also provide you with an insight on our thought process which led to this decision.

This paper is not intended to be a treatise on baghouse technology, although we have dealt with many technical considerations. Rather, it is basically one of philosophy, which I hope will clearly outline our reasons for making a decision which apparently to some appears incredible.

The Tennessee Valley Authority is a Federal government-owned and government-operated electric utility with a current generating capacity of 27 million kilowatts and over 19 million kilowatts of additional capacity under construction or proposed to keep pace with projected power demands through 1986. By 1987, the total generating capacity is projected to be around 50,000 megawatts.

As of today, we have 12 coal-fired generating plants totaling 63 units which produce nearly 18,000 megawatts of power and burn approximately 40 million tons of coal per year. Based on an average ash content of 15 percent, these plants produce approximately 6 million tons of ash per year and considering 99.5 percent collection efficiency to meet most any regulation, we must collect approximately 4.5 million tons of fly ash per year to meet particulate regulations. If you were to take a building 190 feet square, it would have to be a mile high to hold this much fly ash! So--you can see we need good, dependable ash collection equipment. It is my job as Head Mechanical Engineer in our Division of Engineering Design to design, specify, and support construction activities for equipment that will satisfy the regulatory agencies requirements and to attempt to accomplish this task with the best overall solution consistent with good engineering practice and economy.

Let's take a brief look at TVA's past and present particulate control activities.

Slide 1. Show chart and discuss:

1. Overall view of pollution control program.
2. Describe briefly each plant and what was done.
3. Indicate costs will approach $1.2 billion.

Slide 2.

If we plot these expenditures on a curve by the years in which these monies were spent, we generate the curve as shown in slide 3.

Slide 3.

The two vertical dotted lines represent the year in which the Federal standards and the EPA and State standards were enacted. It can be noted that following the passing of the EPA and State standards of 1972, the dollar expenditure began to accelerate in a dramatic fashion.

Between 1972 and 1981, TVA will have spent approximately $1.2 billion for an average of $13 million per year or slightly over $1 million per month.

There have been remarks that TVA is dragging its feet on this pollution control program and perhaps some of you in the private sector of the utility industry have been accused likewise. Pollution control programs such as this and those all of you have are without exception very complicated. Decisions regarding selected control strategies and solutions do not come overnight. Implementation takes even longer.

My point is this: The program shown on charts 2 and 3 will cost about $1.3 billion. Our total plant investment for all plants when originally built is $2.5 billion. I submit that an expenditure of this magnitude, representing 52 percent of total plant investment for air pollution programs is not consistent with a label of "foot dragging." I suspect many companies represented here today might point to similar ratios.

This massive retrofit program is nearing completion. We can see the light at the end of the tunnel--but some of our toughest problems seem to lurk ahead in the shadows.

Show aerial photo slide of Shawnee Steam Plant.

Shawnee Steam Plant was completed in 1957. It is a base load plant consisting of ten 175-megawatt units. As shown on this chart earlier, Shawnee was retrofitted with precipitators between 1968 and 1970 to meet Federal particulate standards of 1966. However, today it does not meet the EPA or State of Kentucky SO_2 or particulate standards which were adopted in 1972.

These standards call for a sulfur emission of 1.2 pounds per million Btu of coal fired and a particulate emission of 0.11 pound of ash per million Btu of coal fired. Our present coal supply has a sulfur content of roughly three to four percent and does not come close to meeting sulfur regulations. The precipitators which were installed between 1968 and 1970 and designed for 98 percent efficiency to comply with the 1966 Federal standards come fairly close to meeting present day regulations, but we are not playing horseshoes and close doesn't count!

There are two control strategies available to us.

Slide 4.

1. Continue to use our present coal supply and install scrubbers to bring us into compliance with both the sulfur and particulate regulations. This would result in a yearly cost of $103 million for amortization, operation, and maintenance.

2. The other strategy would be to switch our coal supply, obtain contracts for western low-sulfur coal to comply with SO_2 regulations, and install more electrostatic precipitators to control particulate. This strategy would cost an estimated $70 million annually for amortization, operation, and maintenance.

Faced with these two alternatives and the prime responsibility of holding power rates as low as possible, it is obvious which control strategy should be followed. Given the option of two strategies--one offering a $600 million saving over the other for the remaining 20-year plant life--it becomes obvious that the low-sulfur coal strategy should be pursued.

You are all familiar with the various problems and uncertainties of using electrostatic precipitators with western low-sulfur coal.

Some very large precipitator installations have operated successfully on western coal and there are also some which have not performed so well! This brings us, then, to why I am here today.

"What are TVA's views on fabric filters and how did this lead to our purchase of ten structural baghouses?"

In analyzing TVA's current needs at Shawnee, one question needed to be answered: Why should TVA buy a structural baghouse? Or more appropriately, why shouldn't TVA buy an electrostatic precipitator? The answer to these questions launched a series of complex evaluations which at first raised more questions than answers. These evaluations spanned over a period of nearly two years, and it was not until recent court rulings that the project took on its in-depth character.

In the spring of 1976, when we began our studies and cost estimates of scrubbers versus precipitators referred to earlier, our major problem at that time was to assume a precipitator size which could cover most any possible coal supply. In talking with several precipitator vendors, we had recommendations on sizing of anywhere between 550 to 950 SCA for use in budgeting estimates for precipitators to serve an "unknown" western coal. You will agree, I believe, that this very wide range of possible sizes does not represent real solid information on which to size equipment. We looked at our possibilities and, on a very scientific basis, determined that we would select 700 SCA--not because it was about halfway between 550 and 950--but because it represented the largest box we could get in the available space. This, combined with the 100 SCA in the existing units (we reasoned), should be enough!

But will it? Who knows?

We didn't know what coal we were designing for! We simply filled up the available space with all the precipitator surface we could cram in it!

By the spring of 1977, it was clear that a decision must be reached soon for particulate control at Shawnee, since our schedule called for release of particulate control equipment specifications in September. We had been ordered to bring Shawnee into compliance as soon as possible; and since our evaluations indicated low-sulfur coal as the most economically feasible method, we faced the problem of how to write specifications for precipitators without a firm source of coal. Some vendors will not bid on precipitators for a western low-sulfur coal without benefit of pilot test results on ash resistivity, migration velocity, dust particle size and distribution, etc., and some will not bid even then!

Our problem, then, was easily defined: How do we size a precipitator and have any degree of confidence that it will perform as required on any western low-sulfur coal for the next 20 odd years?

Let's look at some of the wide variations in western coals.

Slide 5. Discuss three major groups.

Slide 6. Broad brush chart--discuss wide range of sizing possibility.

I believe this illustrates graphically why we were given the wide range for sizing of anywhere between 550 and 950 SCA by vendors. Now, let's consider the possible solutions:

1. One solution, time permitting, would be to run pilot tests on coal. But which coal? Precipitator manufacturers want a specific analysis when bidding western coal. "Is this the actual coal you will be burning?"--they ask. When faced with guarantees and bonus penalty provisions, they have to be cautious, and we really can't fault them for that.

2. Another possibility is to establish a firm, permanent source of coal, run pilot tests on it, and specify accordingly. However, our purchasing regulations of competitive bidding prevent this being done--but even then there is doubt in my mind that a long-term coal contract in today's market could be accomplished.

3. The third possibility then is back to our original assumption--put in all the surface we can cram in the space and with tongue in cheek say, "There is our solution--that will put us in compliance and keep us there--we hope!"

   In our 20 years of buying and installing 128 precipitators we have noted the evolutionary process in the art of designing them, but never have we faced, knowingly, this sort of hit-and-miss approach! It does not represent the type of information on which solid engineering decisions have been made at TVA.

4. There is another possible solution to our problem at Shawnee. We believe it is a more positive one than the three just mentioned and that it offers a much less degree of uncertainty for this specific situation.

You must know by now that I refer to the use of structural baghouses for controlling particulates of western low-sulfur coal at Shawnee. I believe they are a viable solution to our problem and will provide us with flexibility in establishing coal contracts while remaining insensitive to changes in coal supplies.

Therefore, in late fall of 1976, I had directed my staff to assemble a preliminary set of baghouse specifications for Shawnee Steam Plant, written to accomplish two motives. The first of these was to determine the flange-flange installed cost for a structural baghouse. The second motive was to test the market for its receptiveness to TVA specifications. Seven invitations were sent out and six returned. All six responses set the stage and our evaluations began.

This evaluation compared a baghouse installation to a precipitator installation at Shawnee with all site specific factors included. Since Shawnee is a base load plant, even though it is some 20 odd years old, it was reasonable to assume a 20-year remaining life. So we used a 20-year life.

These evaluations were completed in the spring of 1977 and formed the basis for our decision.

Slide 7. This chart shows the basic design parameters used in our comparison. Discuss chart.

Slides 8, 9, and 10. Discuss arrangement.

Let's talk about the basic items considered in this overall evaluation.

1. Capital Cost

   This item includes the installed cost of equipment and all auxiliaries including design, overheads, contingency, and interest during construction.

2. Power Requirements

   The Shawnee Steam Plant baghouse complex will require additional induced-draft fan capability due to the added differential pressure across the baghouse and ductwork. TVA analyzed the power requirements looking at both the evaluated and expected power. We did not look at common items, such as power for guillotine dampers, control rooms, ash systems, lighting, elevators, and hoists. But we did look at power for isolation dampers, induced-draft fans, T/R sets, heaters, and rapper systems. The evaluated power requirements were assumed to be 8-inch SPWG across the baghouse and 1-inch SPWG across the precipitator. In the expected power requirements, the pressure drop across the baghouse was assumed to be 3-inch SPWG. If we assign the precipitator power requirements a factor of 1.0, the evaluated power for the baghouse at 8-inch SPWG is 1.74, and the expected at 3-inch SPWG is 0.93. This clearly shows that if the differential pressure across the baghouse can be maintained around 4-inch SPWG, then the power requirements will be about the same as for a precipitator. This is an appealing point since it also states if the power requirements can be held under the 4-inch SPWG, we can operate our pollution abatement equipment at less than we expected and increase our net megawattage output. We at TVA feel this is a desirable goal and believe the industry can supply equipment to meet our needs.

3. Maintenance Costs (Labor and Material)

TVA's baghouse maintenance evaluation included an average bag replacement of both two and three years and ten percent of all operators on dampers replaced over the plant life. The precipitator maintenance/evaluation included the normal life of T/R's, heaters, and rappers. The results of this evaluation are as follows: With the precipitator assigned a factor of 1.0, the baghouse resulted in an 8.25 and 5.51 factor for two- and three-year bag life respectively. This high factor is clearly a result of changing out the bags at periodic intervals.

The overall economic evaluation of capital cost, power requirement costs, and maintenance costs indicated a factor for the baghouse of 0.8 using a two-year bag life and 0.76 using a three-year bag life when compared to the precipitator of 1.0.

These ratios indicate an overall evaluated saving when considering capital cost, power requirements, and maintenance costs of 20 to 24 percent depending on whether you consider a two-year or a three-year bag life.

To be specific, these ratios correspond to an overall savings of $28 million when using 8-inch pressure drop and two-year bag life and up to $40 million when using 3-inch pressure drop and a three-year bag life.

We believe these overall ratios and corresponding dollar values are significant and deserve careful consideration prior to committing to a long-term decision.

Our study further shows that depending on pressure drop and estimated bag life, there is a break-even point of between 500 and 540 SCA above which it is definitely more economical to install baghouses.

Slide 11. The situation then at Shawnee boils down to this question.

"How do we best assure ourselves of meeting particulate standards with an unknown, but certainly fickle, western low-sulfur coal?" Whatever we do at Shawnee has to be the fix. A second chance would be of little value because all available space will be used up.

In consideration of all these factors, I do not believe our "degree of uncertainty" for particulate control is as great with baghouses as it is by using precipitators. To put it more positively, I believe that our best chance for meeting particulate standards on a long-term continuous basis at Shawnee and doing so more economically will be by using baghouses. Therefore, after management approval in May 1977, specifications were prepared and proposals invited which ultimately led to contract award this past March.

This evaluation and resulting contract award is not to say that TVA is abandoning electrostatic precipitators and pushing baghouse technology in their place. Far from it!

At the present time, we have invitations out for 12 precipitators at our Cumberland Steam Plant and have just awarded a contract for installation of four at our Paradise unit 3 plant.

We are saying, as we have tried to show in this evaluation, that given certain conditions, such as difficult coals, uncertain coal supplies, and stringent regulations, there is a point for any given application where a baghouse may make technical and economic sense, and that evaluations should be made in these individual cases to determine the best long-range control strategy.

Since this evaluation was made based on western low-sulfur coal, a decision has been made that TVA will use eastern low-sulfur coal. However, this does not change our basic philosophy of using baghouses since the eastern low-sulfur coals also require very large precipitators.

I have shown you our basic considerations for the overall evaluation at Shawnee, and now I would like to say a few words about what TVA and other utilities might expect of the baghouse or fabric filter industry.

A steam plant must operate with the pollution abatement devices being dependent on the power plants' requirements and not the power plant being dependent on the pollution abatement devices. The goal is to generate electrical power and not operate a dust collector that you have to worry about burning up bags or some other cataclysmic event. The baghouse system must be completely automatic with a bypass system for high temperature in case of air heater upsets, have an alarm system with manual overrides to clean the cloth, and operate in a manner to accomplish the above stated goal. The results of our design study indicated that such a system could be installed.

In order to assure this reliability, quality specifications must be generated. Some suggested items to assure this quality are listed below:

1. A minimum guaranteed bag life of two years. (There are instances where some bags have already lasted three and four years.)
2. Stainless steel bag hardware.
3. Cor-Ten steel on all other gas contact surfaces.
4. Air to cloth ratio of 2:1 gross and not exceeding 2.5:1 with one compartment out for maintenance and one compartment out for cleaning.
5. 12-Inch-diameter by 30-foot-long bags of glass fabric with Teflon B finish.
6. Complete controls that offer flexibility in cleaning and maintenance of the baghouse.
7. Complete access to all levels.
8. High-quality expansion joints and dampers.
9. Complete erection and startup services.
10. Instrumentation to detect and identify excessive pressure drop in compartments.
11. Some sort of guarantee related to excessive pressure drop.
12. Spare reverse air fans.
13. Maximum 2-bag reach.

What About the Future?

1. I agree with some of the recent publications that the utility industry will see a sharp increase in the use of baghouses in the next few years. This increase will come about because of reasons we have shown here this morning, i.e.:
    a. Uncertainties of coal supplies.
    b. Changing regulations.

   c. The ever-increasing size of precipitators to handle difficult ash.

   d. Economics.

   e. Improvements and modernization of baghouse design.

2. Bag life must and will be improved. There is much work presently being done in this area. I do not think it is unreasonable for the utility industry to expect and even get bag life guarantees of up to five years in the near future. New materials will be developed to increase bag life and very likely permit higher air to cloth ratios which could ultimately reduce costs.

3. Auxiliary equipment, such as poppet valves and their operators, will and must be designed and built to give tight shutoff and long service life.

4. Cleaning cycles will be optimized to increase bag life.

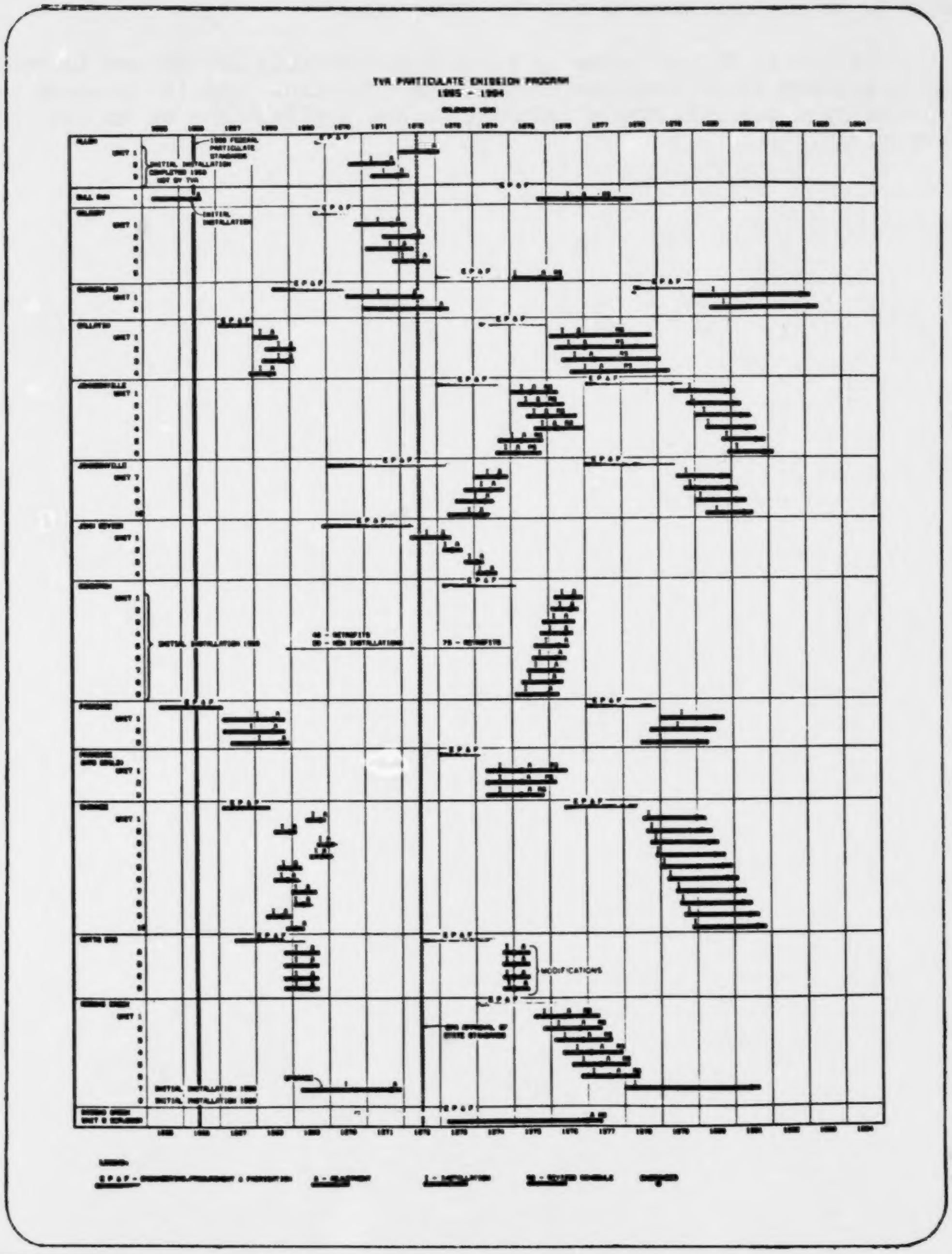
The future of fabric filters depends on this industry's response to these items and the needs of the utilities. Their equipment will collect dust at ultra-high-efficiency levels--no doubt about this. However, fabric filter suppliers must accept the challenge and supply top-drawer equipment which will collect dust on a long-term, round-the-clock basis and at competitive costs. The utility industry will demand it.

I believe this can and will be done to the extent that we at TVA have committed an $80 million project for ten units at Shawnee to this technology.

So, there we have it--a commitment to an $80 million baghouse installation. If anyone had told me five years ago that I would be spearheading a decision to install baghouses at Shawnee or anywhere else, I would have replied, "You are crazy!" You see--not too long ago, the utility industry looked down their nose at baghouses. They had very high pressure drop--bag life was very short and operating and maintenance costs were very high. And besides that, they were old fashioned and for industrial and other uses, they were just not sophisticated enough for the utility industry.

However, today we are operating under completely different economic and regulatory conditions, and these conditions are not as yet completely stable; but, fortunately, technology as most always is rising to meet the challenge. We cannot meet present day needs and requirements by continuing to solve our problems as we have in the past by using traditional or even totally tested solutions. We must examine each new situation on its own merit--and possibly arrive at solutions which may appear innovative. Of such stuff progress is made. There are today--successful baghouse installations within the utility industry--and there will be more to come--none perhaps as large as Shawnee, but since when do we measure success only by sheer size?

The fabric filter industry is on the threshold of new and increased participation in particulate control for utilities, and its success depends upon the industry's response to new applications of an old technology.



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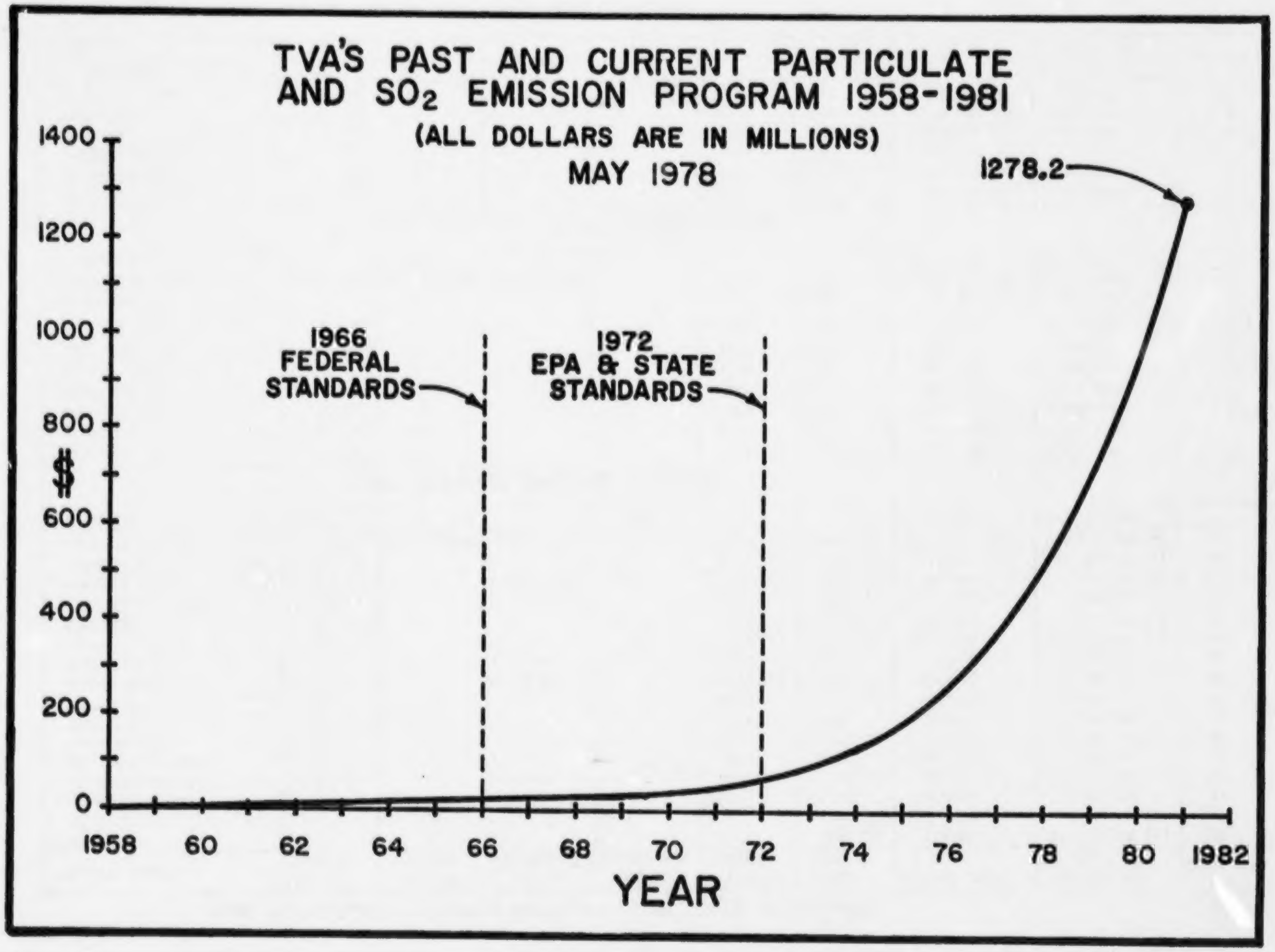
TVA'S PAST AND CURRENT PARTICULATE & SO_2 EMISSION PROGRAM 1958-1978

NEW PARTICULATE EMISSION PROGRAM - 1972 STATE STANDARDS

PLANT NAME	NO. OF UNITS	NO. OF PRECIPS.	NO. OF SCRUBBERS	NO. OF BAGHOUSES	START CONST.	COMPL. CONST.	PLANT CAP. (KW)	INSTALLED COST	COST / KW
BULL RUN	1	4			10/75	5/78 (c)	950,000	$31,000,000 (c)	$33
GALLATIN 1-4	4	4			9/76	1/79 (c)	1,255,200	37,000,000 (c)	29
JOHNSONVILLE 1-6	6	6			4/74	9/77	794,000	18,500,000	23
JOHNSONVILLE 1-6	6 (a)		5 TRAINS		9/79 (c)	12/81 (c)	794,000 (a)	130,000,000 (c)	164
JOHNSONVILLE 7-10	4	5			4/73	9/77	691,200	8,500,000	12
KINGSTON 1-9	9	9			2/74	2/78	1,723,250	64,000,000 (b)	37
COLBERT 5	1	2			4/74	2/78	550,000	13,200,000	24
WIDOWS CREEK 1-6	6	6			10/74	6/78 (c)	852,975	60,000,000 (b,c)	70
WIDOWS CREEK 7	1		4 TRAINS		11/78 (c)	3/81 (c)	575,010	54,000,000 (c)	94
WIDOWS CREEK 8	1		4 TRAINS		1/71	12/76	550,000	54,000,000	98
SHAWNEE 1-10	10			10	5/78 (c)	9/81 (c)	1,750,000	80,000,000 (c)	46
CUMBERLAND 1 & 2	2	12			3/79 (c)	12/81 (c)	2,600,000	90,000,000 (c)	35
CUMBERLAND 1 & 2	2 (a)		2 TRAINS/UNIT		7/79 (c)	7/82 (c)	2,600,000 (a)	70,000,000 (c)	27
PARADISE 1 & 2	2		6 TRAINS/UNIT		7/79 (c)	4/82 (c)	1,408,000	335,000,000 (c)	213
PARADISE 3	1	4			9/78 (c)	9/80 (c)	1,150,200	28,000,000 (c)	24
PARADISE 1-3	3 (a)	COAL WASHING PLANT			4/78 (c)	12/80 (c)	2,558,200 (a)	130,000,000 (c)	51
SUBTOTALS	48	51		10			14,849,835	1,203,200,000	
FIRST RETROFIT PROGRAM 1958-1972									
KINGSTON 1-9	9 (a)	9			8/58	4/61	1,723,250 (a)	3,273,000	2
SHAWNEE 1-10	10 (a)	10			5/68	5/73	1,750,000 (a)	9,161,000	5
GALLATIN 1-4	4 (a)	4			11/68	4/71	1,255,200 (a)	5,462,000	4
ALLEN 1-3	3	3			11/70	12/73	990,000	10,114,000	10
COLBERT 1-4	4	4			11/70	5/74	869,750	8,320,000	10
JOHN SEVIER 1-4	4	4			4/72	8/74	846,500	11,785,000	14
PARADISE 1&2	2 (a)	4			11/59	5/63	1,408,000	3,546,000	2.5
WATTS BAR 1-4	4	4			3/68	5/70	240,000	1,837,000	8
WIDOWS CREEK 7	1 (a)	MOD. TO ORIG. PRECIPITATORS			4/69	5/72	575,010 (a)	1,216,000	2
SUBTOTALS	41	42					9,657,710	54,714,000	
INSTALLED DURING PLANT CONSTRUCTION									
COLBERT 5	1 (a)	2			3/59	10/63	550,000 (a)	875,000	2
WIDOWS CREEK 7	1 (a)	2			11/57	2/61	575,010 (a)	1,424,000	1
WIDOWS CREEK 8	1 (a)	2			10/60	10/64	550,000 (a)		
BULL RUN	1 (a)	4			12/60	11/65	950,000 (a)	1,954,000	2
PARADISE 3	1 (a)	2			1/65	1/70	1,150,200 (a)	3,100,000	3
CUMBERLAND 1&2	2 (a)	12			7/67	4/73	2,600,000 (a)	12,908,000	5
SUBTOTALS	7	24					6,375,210	20,261,000	3
TOTALS	63	117		10			17,796,085	1,278,175,000	

NOT INCLUDED IN COLUMN TOTALS - THESE UNITS LISTED TWICE
INCLUDES NEW STACKS
ESTIMATED



TVA'S PAST AND CURRENT PARTICULATE AND SO_2 EMISSION PROGRAM 1958-1981

(ALL DOLLARS ARE IN MILLIONS)

MAY 1978

SHAWNEE STEAM PLANT

UNITS 1-10

SO_2 AND PARTICULATE CONTROL STRATEGY

MAY 1977

ANNUAL COST	SCRUBBERS	PRECIPITATORS
AMORTIZATION OF INVESTMENT	$ 45,000,000	$31,000,000
ANNUAL O&M	58,000,000	39,000,000
TOTAL ANNUAL COST	$103,000,000	$70,000,000

SHAWNEE STEAM PLANT

UNITS 1-10

LOW SULFUR WESTERN COAL

CATEGORIZED BY EASE OF COLLECTABILITY

MAY 1977

GROUP A - FUELS EASILY COLLECTABLE

	BELLEAYR	EAST DECKER	GILLETTE
MOISTURE	30.0	25.0	34.0
SULFUR	0.3	0.5	0.3
ASH	6.0	5.0	5.0
Na20	1.5	7.2	1.57
K20	0.5	0.4	0.6
CaO	25.0	15.4	19.2
Fe203	4.1	5.26	4.3

GROUP B - FUELS WITH MODERATE COLLECTION PROBLEMS

	NAUGHTON	BLACK MESA	CENTRALIA
MOISTURE	21.0	10.3*	23.0
SULFUR	0.7	0.5	0.35
ASH	8.0	10.4	14.0
Na20	0.3	1.5	1.5
K20	1.2	0.6	0.7
CaO	2.3	7.8	7.0
Fe203	6.0	5.8	5.5

GROUP C - FUELS WHICH HAVE CAUSED DIFFICULT COLLECTION PROBLEMS

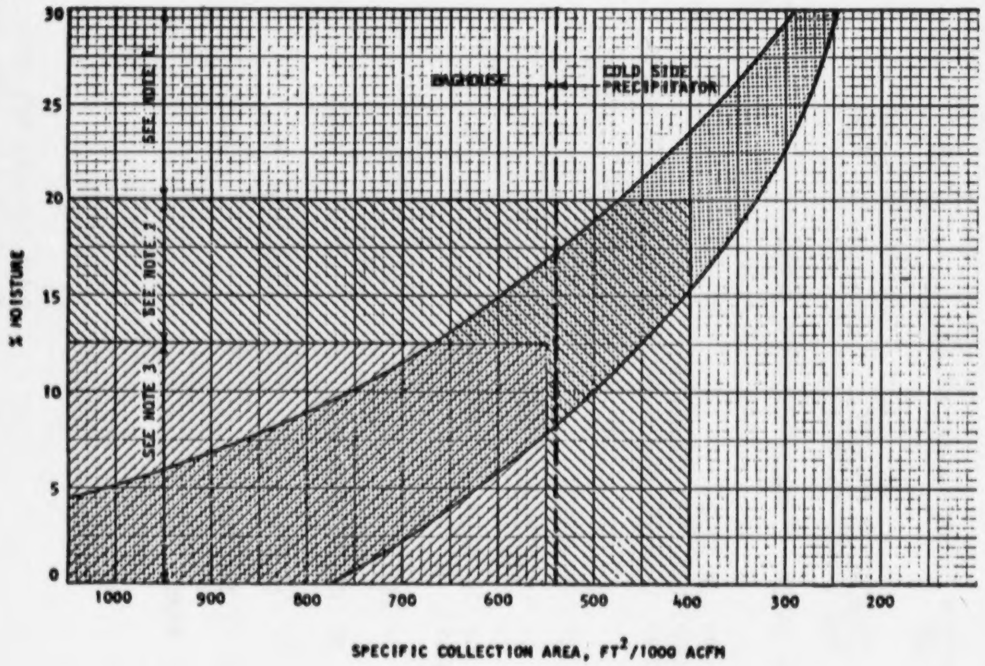
	ARCH MINERAL	MEDICINE BOW	COLSTRIP
MOISTURE	10.0	11.8	25.0**
SULFUR	0.6	0.55	0.7
ASH	12.0	9.8	8.0
Na20	0.9	0.2	0.4
K20	0.1	1.0	0.5
CaO	26.0	13.0	13.0
Fe203	7.0	9.5	8.0

*Fuel is slurried and pumped to the power plant giving H_2O levels up [illegible] 22 percent at the boiler.

**Fuel moisture has recently shown a remarkable shift in character across the seam with moisture levels as low as 12.0 percent.

3

FIGURE 1: COLLECTION OF FLY ASH FROM WESTERN LOW-SULFUR COAL, % MOISTURE VERSUS SPECIFIC COLLECTION AREA



NOTES:

1. FLY ASH FROM COAL IN THIS MOISTURE RANGE CAN BE READILY COLLECTED BY "COLD SIDE" ELECTROSTATIC PRECIPITATORS.
2. IF A SPECIFIC COAL CAN BE DETERMINED IN THIS RANGE, A "COLD SIDE" PRECIPITATOR CAN BE DESIGNED TO FUNCTION PROPERLY. HOWEVER, IF THE COAL SUPPLY IS NOT DEFINITE PRECIPITATORS DESIGNED FOR THIS RANGE CAN BE ECONOMICALLY UNFEASIBLE AND COULD RESULT IN DISASTER PERFORMANCE WISE.
3. FLY ASH FROM COAL WITH MOISTURE CONTENT IN THIS RANGE IS VERY DIFFICULT TO COLLECT WITH A "COLD SIDE" PRECIPITATOR. SOME MANUFACTURERS WILL NOT EVEN QUOTE EQUIPMENT IN THIS RANGE. IN THIS CASE, IT IS ALMOST MANDATORY TO CONSIDER "HOT SIDE" PRECIPITATORS OR SOME OTHER METHOD OF CONTROL.

% MOISTURE
VS
SCA

TENNESSEE VALLEY AUTHORITY

49M1 MSCA577

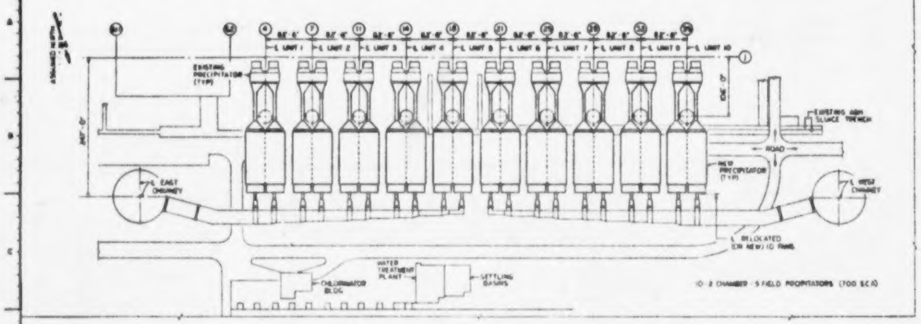
SHAWNEE STEAM PLANT

UNITS 1-10

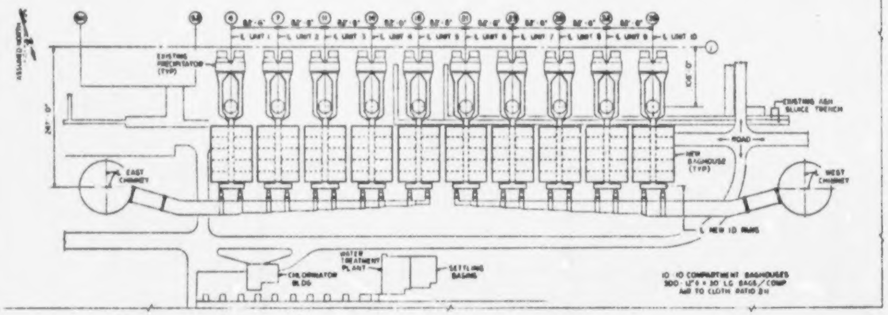
DESIGN PARAMETERS

PARAMETER	COLDSIDE PRECIPITATOR	STRUCTURAL BAGHOUSE	
VOLUME/BOILER MACFM	585	585 NORMAL. 642 NORMAL W/ REVERSE AIR.	
TEMPERATURE, DEGREE F	325	325	
EFFICIENCY - %	99.6	99.6+	
MIGRATION VELOCITY CM/SEC	4.0	--	
COLLECTION SURFACE AREA/BOILER, M FT^2	410	325	
SCA - $\frac{\text{COLLECTION AREA FT}^2}{\text{GAS VOLUME MACFM}}$	700	--	
FILTER RATIO, VOLUME/COLLECTING SURFACE	--	NORMAL OPERATION	NORMAL OPERATION W/REVERSE AIR
ALL COMP. ON LINE		1.79	1.96
ONE COMP. DOWN FOR CLEANING		1.99	2.18
ONE COMP. DOWN FOR CLEAN.& ONE COMP. DOWN FOR MAINT.		2.23	2.46
EQUIPMENT SELECTION			
NO. OF COLLECTORS/BOILER	1	1	
NO. OF CHAMBERS OR COMPARTMENTS/ BOILER	2	10	
NO. OF FIELDS	5	--	
NO. OF BAGS/COMPARTMENT	--	324	
NO. OF T/R SETS	12	--	
REVERSE AIR FANS	--	1*	
I.D. FANS	--	2	

*MAIN REVERSE AIR SUPPLIED BY DRAFT ON I.D. FANS, REVERSE AIR FAN BACKUP SYSTEM.


4
ASSUMED NORTH
EXISTING PRECIPITATOR (TYP)
82'-6"
℄ UNIT 1
℄ UNIT 2
℄ UNIT 3
℄ UNIT 4
℄ UNIT 5
℄ UNIT 6
℄ UNIT 7
℄ UNIT 8
℄ UNIT 9
℄ UNIT 10
247'-0"
106'-0"
℄ EAST CHIMNEY
℄ WEST CHIMNEY
EXISTING ASH SLUICE TRENCH
ROAD
NEW PRECIPITATOR (TYP)
℄ RELOCATED (OR NEW) ID FANS
CHLORINATOR BLDG
WATER TREATMENT PLANT
SETTLING BASINS
10 - 2 CHAMBER - 5 FIELD PRECIPITATORS (700 SCA)

KEY PLAN
PRECIPITATOR


ASSUMED NORTH
EXISTING PRECIPITATOR (TYP)
82'-6"
℄ UNIT 1
℄ UNIT 2
℄ UNIT 3
℄ UNIT 4
℄ UNIT 5
℄ UNIT 6
℄ UNIT 7
℄ UNIT 8
℄ UNIT 9
℄ UNIT 10
247'-0"
106'-0"
℄ EAST CHIMNEY
℄ WEST CHIMNEY
EXISTING ASH SLUICE TRENCH
ROAD
NEW BAGHOUSE (TYP)
℄ NEW ID FANS
CHLORINATOR BLDG
WATER TREATMENT PLANT
SETTLING BASINS
10 - 10 COMPARTMENT BAGHOUSES
300 - 12"⌀ × 30' LG BAGS/COMP
AIR TO CLOTH RATIO 2:1

KEY PLAN
BAGHOUSE

SCALE 1" = 60'-0" EXCEPT AS NOTED

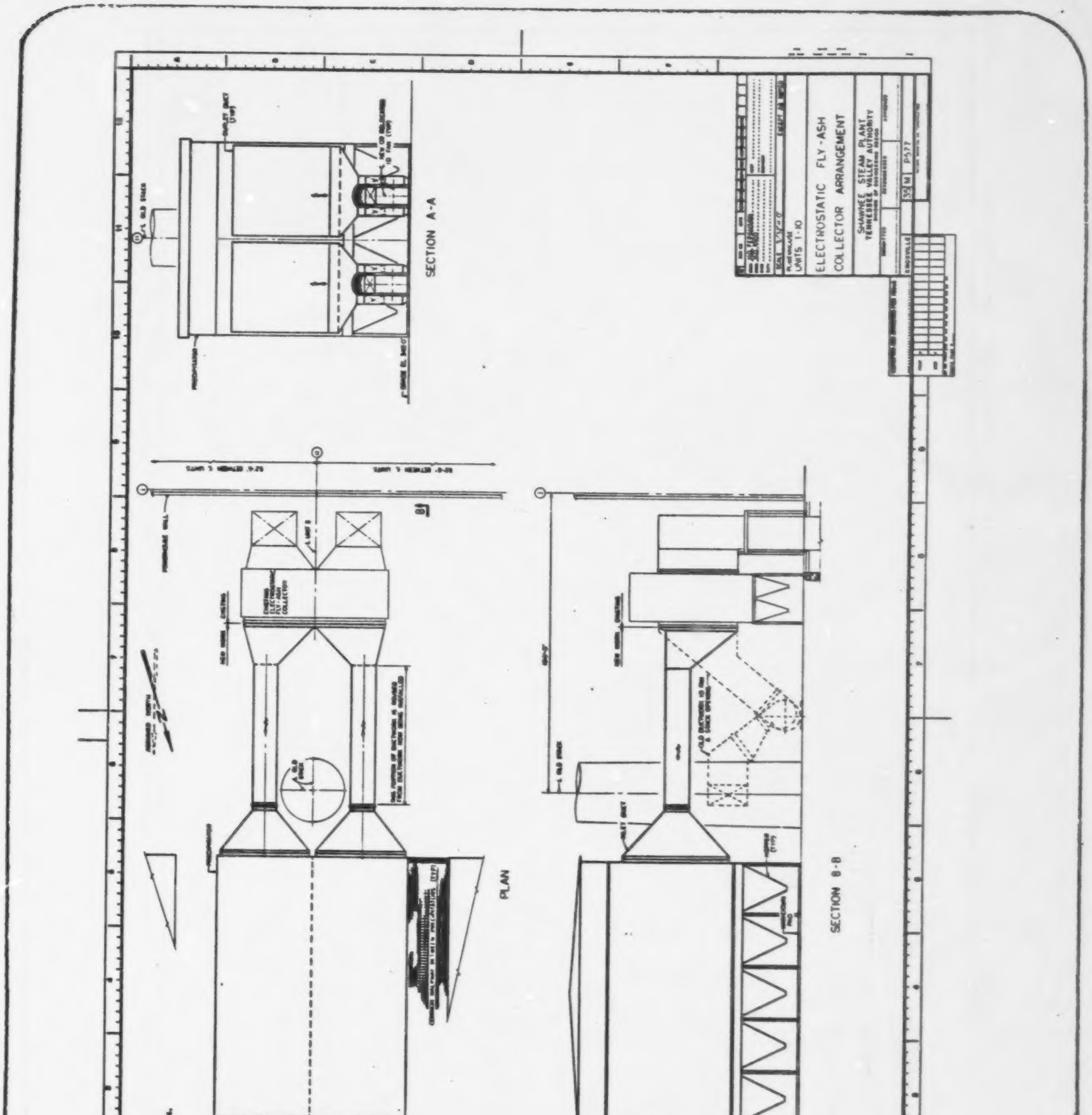
POWERHOUSE
UNITS 1-10

KEY PLAN
PRECIPITATOR/BAGHOUSE

SHAWNEE STEAM PLANT
TENNESSEE VALLEY AUTHORITY
DIVISION OF ENGINEERING DESIGN

SUBMITTED
RECOMMENDED
APPROVED

KNOXVILLE
35 M PBH577


SECTION A-A
PLAN
SECTION B-B
UNITS 1-10
ELECTROSTATIC FLY-ASH
COLLECTOR ARRANGEMENT
SHAWNEE STEAM PLANT
TENNESSEE VALLEY AUTHORITY
KNOXVILLE
39 M P577

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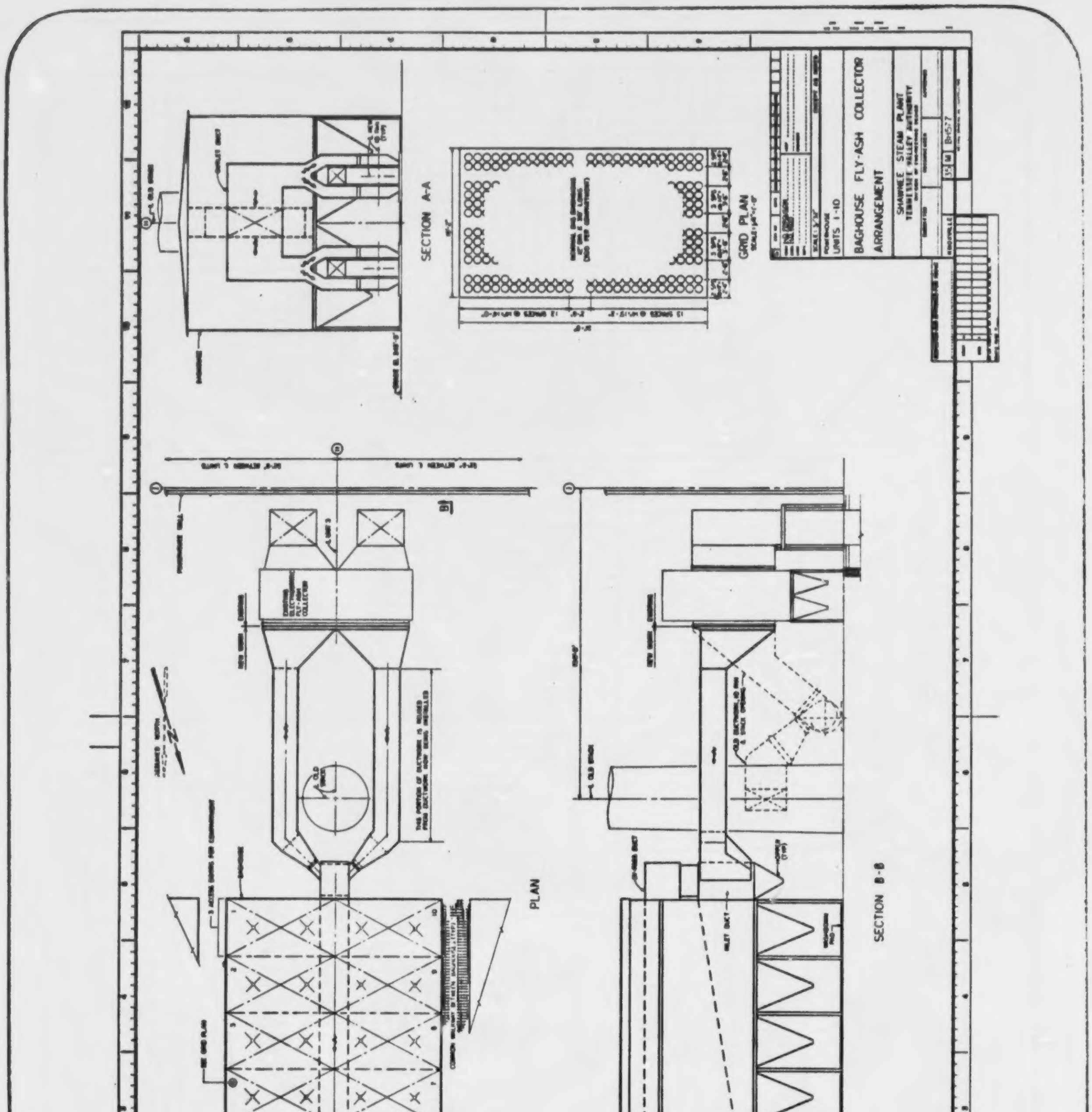
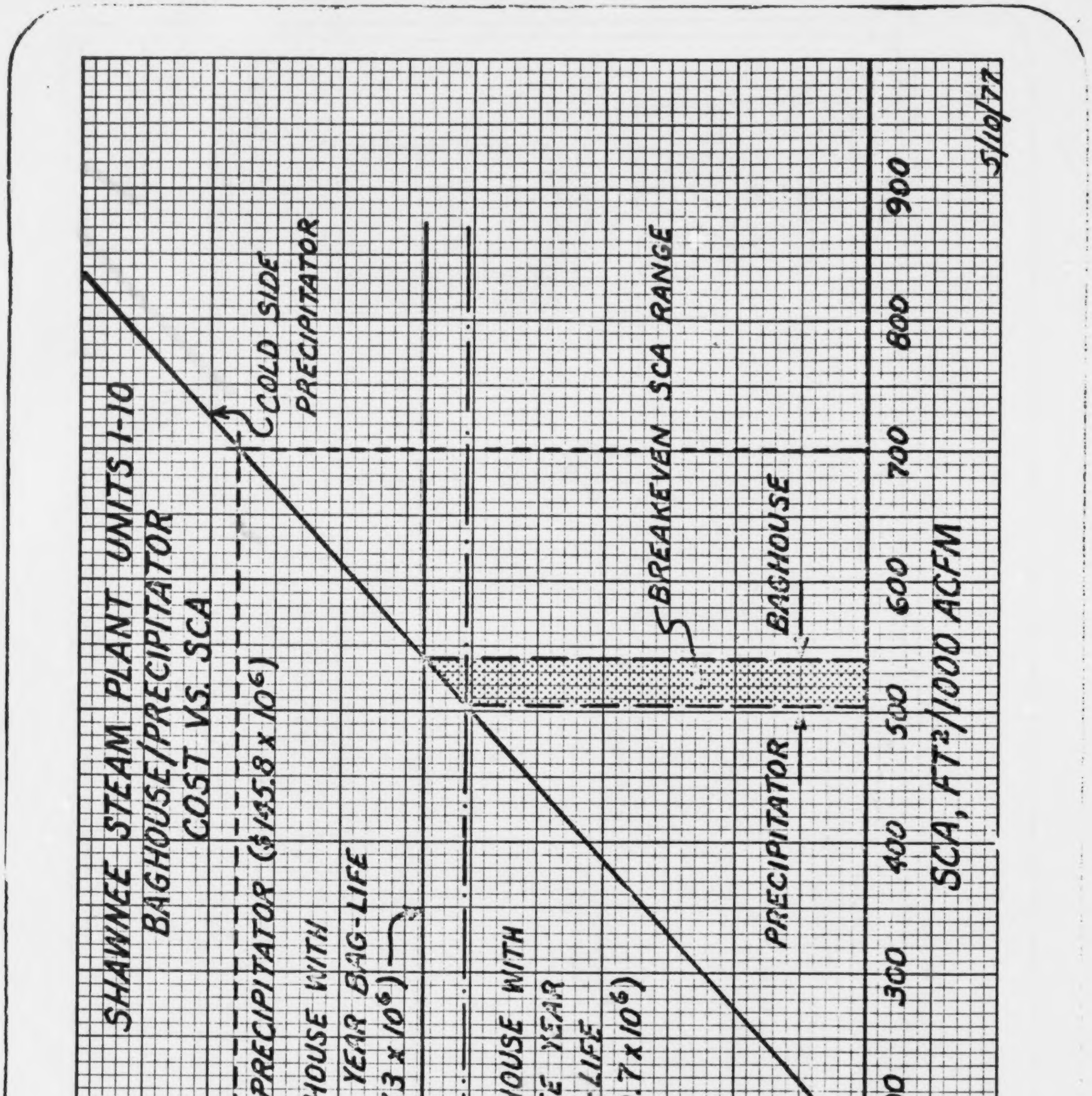

SECTION A-A
GRID PLAN
PLAN
SECTION B-B
POWERHOUSE
UNITS 1-10
BAGHOUSE FLY-ASH COLLECTOR ARRANGEMENT
SHAWNEE STEAM PLANT
TENNESSEE VALLEY AUTHORITY
B-527


SHAWNEE STEAM PLANT UNITS 1-10
BAGHOUSE/PRECIPITATOR
COST VS. SCA
PRECIPITATOR ($143.8 x 10^6)
BAGHOUSE WITH
TWO YEAR BAG-LIFE
($117.3 x 10^6)
BAGHOUSE WITH
THREE YEAR
BAG-LIFE
($110.7 x 10^6)
COLD SIDE
PRECIPITATOR
BREAKEVEN SCA RANGE
PRECIPITATOR
BAGHOUSE
EVALUATED INSTALLED COST, $$10^6$
150
140
130
120
110
100
90
80
70
60
200
300
400
500
600
700
800
900
SCA, FT²/1000 ACFM
5/10/77

HIGH RATIO FABRIC FILTERS
FOR UTILITY BOILERS

B.L. ARNOLD
FLAKT, INC.
OLD GREENWICH, CONNECTICUT

B. MELVILLE
FLAKT CANADA LTD.
OTTAWA, ONTARIO

INTRODUCTION

The worldwide Utility Industry is today faced with complex decisions regarding the selection of pollution control equipment. These decisions must be based on the latest technology available today and they must also meet the requirements of full scale operation a few years from now when the units come on-line. It is the intent of this Paper to show that the pulse type fabric filter is a viable option for the collection of particulate from coal fired boilers.

It has recently become the practice to select a range of operating conditions for a plant to evaluate the cost of an electrostatic precipitator versus a low ratio fabric filter and arrive at a set of decision curves. Based on these decision curves, a precipitator or a fabric filter is found to be the more economical alternative for that particular case. It is extremely important that the full range of possible operating conditions for an individual project be evaluated as the decision curves must be comprehensive.

It is not correct to generalize and say that for coals of a certain sulphur content a precipitator of a specified collecting area is required, nor is it any more reasonable to say that above a certain size of electrostatic precipitator a fabric filter will be the more economical alternative. Each individual case must be evaluated on its own parameters such as the operating conditions of the plant, cost of capital, possible future legislations.

In order to determine the most economical alternative for a particular project, it is necessary first to review the actual alternatives available and these now include the electrostatic precipitator, the low ratio fabric filter and the high ratio fabric filter.

In carrying out an evaluation a number of criteria must be considered and the decision towards the use of a fabric filter would be enhanced by the presence of any of the following:

- high resistivity dust to be collected
- a demand for collecting efficiencies in the high 99.8 plus range
- expected regulations concerning sub-micron particles
- requirements for efficient removal of toxic trace elements from the flue gas
- strict opacity requirements
- the capability to accept variations in coal properties while maintaining the required collecting efficiency

It is thus evident that many factors would support the selection of a fabric filter collector for flyash collection.

The evaluation for a fabric collector should include the alternatives of both low ratio (inside bag collector) and high ratio (outside bag collector) and include the comparison of such items as:

- cost of the initial capital equipment
- operating costs
- maintenance costs
- bag replacement costs
- space requirements

INSIDE AND OUTISDE BAG COLLECTORS

Inside Bag Collectors

With the Inside bag collector or "low ratio collector" the particulate is collected on the inside of the bags. Figure-1 illustrates this basic feature of an inside bag collector. The bags are attached at the cell plate at the lower end of the bag and supported from a tensioning device at the top of the bag. The particulate-laden gases enter the filter below the cell plate through the hopper area, enter the bag inlet at the bottom of the collector compartment, then pass through the fabric bag from the inside to the outside. The gases then flow between the bags and leave the compartment at the top. All the particulate-laden gases are thus forced to pass through the relatively small circular bag inlet at the cell plate. The inlet geometry of the inside bag collector thus limits the air to cloth ratio as a too high inlet velocity would invariably cause bag wear at the lower end of the bag and result in a dramatic reduction in bag life. In order to reduce the risk of wear at the lower end of the bag, the bag inlets are equipped with steel thimbles for protection from abrasion. Various means of cleaning these inside type bags are employed ranging from reverse air, to shaker, to a combination of the two.

As the dust is collected on the inside of the bag, the compartment must be taken off-line when it is being cleaned thereby allowing the dust to fall out through the circular opening in the bottom of the bag. The filter plant must thus be dimensioned to enable at least one compartment to be off-line for cleaning without exceeding the specified pressure drop of the overall system.

The filter media used in the low ratio filters are usually various types of woven fabrics, the selection being dependent on such things as the gas and dust composition and gas temperature.

Outside Bag Collectors

The Outside bag collector or "high ratio collector" collects the particulate with a gas flow from the outside to the inside of the bag. Figure 1 illustrates the basic feature of this collector. The bags in this case are closed at the bottom and the particulate laden gases are introduced around the bags from the side. Each bag is supported on the inside by a metal cage whose prime function is to prevent the bag from collapsing during filtration of the gases.

As the gas passes through the fabric, the dust accumulates on the outside of the bags and the clean gas which has passed through the bags then flows up and out of the top of the compartment. A tube sheet which is located at the top of the bags separates the raw gas side from the clean gas side preventing raw gas from escaping from between the bags to the clean gas side.

The inlet geometry of the high ratio filter thus offers a large cross section for the raw gas flow resulting in a lower initial impingement velocity. This in turn allows for a larger flow per unit of fabric surface, yet in no case does the velocity of the dust laden gas exceed the critical limits at which abrasion starts to be significant. The gas leaves the inside of the bag through the top at a relatively high velocity, however, at this point the gas is clean and consequently is not abrasive to the bags.

The higher air-to-cloth ratio outside bag collector normally utilizes the felted type fabric in order to keep the system pressure drop at a reasonable level. The pressure drop for the high-ratio and low-ratio filters is of the same order of magnitude.

The felted fabric however, allows the particles to penetrate deeper into the material of the bag and a more effective method of cleaning is required. The bag must receive a sufficient impulse to be effectively cleaned.

The cleaning of the high ratio filter is accomplished by a pulse jet technique which consists of a pulse of air introduced into the open top of the filter bag. The pulse air expands the bag suddenly and the dust which has accumulated on the outside of the bag is dislodged and collected in the hopper below. This pulse cleaning operation is carried out either with the unit on-line or off-line depending on a number of factors such as filter bag material, application, and the basic design principles utilized.

TRADITIONAL PULSE

The traditional concept of the pulse type filter utilizes a strong jet of compressed air which is introduced into the filter bags through nozzles above the top opening of the bag. At the top of each bag a venturi device is utilized to inject additional air down into the bags. The pulse of air plus the injected air travels down within the bag and drives the bag away from the supporting cage, dislodging the dust which has deposited on the outside of the bag. The air pressure in the tanks supplying the air for cleaning is as high as 5 to 7 atmospheres and the operation is controlled by a valve placed after the tank. The traditional pulse jet system requires relatively high power demands. Furthermore, the air pulse injected down into the bag is often not efficient enough to clean bags of extended lengths thus restricting the use of the traditional pulse jet system.

The traditional geometry of the high pressure pulse jet is seen to the left of Figure 2. The tank pressure is 5 to 7 atmospheres and with the ejected pulse principle, a secondary air flow 6 to 7 times larger than the primary air flow is ejected into the bag through the venturi. The efficiency of the venturi is relatively low and therefore a considerable power loss results. The pulse is slowed down and loses its cleaning power rather quickly.

LOW PRESSURE PULSE

The low pressure pulse jet has considerable advantages with regard to power demands and pulse efficiency.(Figure 2) In this design a diaphram valve is an integral part of the pulse tank.(Figure 3) When the valve is opened the compressed air enters the header for distribution to the bags. The peak pressure in the header is obtained almost immediately and this combined with a very quick acting valve results in a greatly reduced pulse air requirement.(Figure 4) The result is a low pressure, high effective energy, pulse system.

EQUIPMENT INTRODUCTION

As a supplier we recognize that prior to successfully introducing equipment into a market there are a number of steps to be followed such as: laboratory analysis and testing, field testing and full scale demonstration plants.

LABORATORY ANALYSIS AND TESTING

When adapting existing fabric filter technology to a new application, it is a complex procedure to arrive at the optimum combination of filter media, filter design, and the method of cleaning. Flakt has very successfully carried out these procedures when introducing their high ratio fabric filter concept to the cleaning of gases from the aluminum industry, the ferro alloy and steel making furnaces and now to coal fired utility plants.

The procedure includes four main steps:

1. Theoretical evaluation of possible fabrics, filter designs and cleaning principles.
2. Laboratory testing of fabrics regarding durability and filtration performance.
3. Pilot or prototype scale testing for on site determination of filtration performance and fabric deterioration.
4. Full scale installation and follow-up.

The theoretical evaluation includes a summary of historical data and experiences from similar applications.

The laboratory testing procedures for fabrics are well established and standardized. The durability test includes evaluation of internal and external abrasion. The performance test includes evaluation of filter resistance, dust deposition, cleaning requirement, filtration efficiency, and an indication of long term performance by accelerated testing.

Pilot testing is carried out either with pilot scale filters or with test filters built for specific processes or purposes. The tests include confirmation of the same parameters as the laboratory tests and an accelerated testing procedure is possible under actual operating conditions. During the past four years the Flakt Organization has performed pilot tests and then installed full scale plants in the aluminum industry in Scotland and Germany, the ferro alloy industry in Norway and the steel making industry in Sweden.

The laboratory testing and pilot testing have been further enhanced by the recent Flakt Installation in Denmark where precipitator internals were replaced by high ratio pulse type fabric filter internals on a 60 MW coal fired utility boiler. During 1977-78, Flakt has carried out comprehensive pilot testing on flyash at three sites, two of which are in western Canada and one in Australia.

In recognition of the need for a demonstration plant in North America and also to gather reliable operating data from a utility boiler installation, Flakt constructed a full scale module of a high ratio pulse unit and installed it on a coal fired utility boiler in western Canada.(Figure 5) The unit was first put into operation in March 1977 and is being utilized to collect data on fabrics, cages and process related operations. The unit is installed on a 300W boiler firing a low sulphur western Canadian coal with typical coal and flyash properties as given in Figure 6.

When an equipment supplier delivers a full scale installation there is usually limited time available for the supplier to carry out tests and evaluate the performance of the delivered equipment under varying operating conditions. The focus of attention is on maintaining operation and not on the study and evaluation of various parameters. With a full scale module installed in parallel to existing process equipment there exists the opportunity of obtaining real time operating experience and in addition there is the possibility of taking the unit off-line to study the immediate effects of process changes. For this reason the full scale demonstration plant was built.

DESCRIPTION OF FULL SCALE DEMONSTRATION/TEST UNIT

A. Physical Description

1. Equipment Layout for Pulse Jet Fabric Filter demonstration/ test unit - The full size module of the Fabric Filter is situated adjacent to an existing Flakt electrostatic precipitator. The gases for the filter testing are extracted from the ducting leading from the air preheater to the precipitator inlet. The temperature of the gases is in the range 325 to 375°F.

   A representative gas and dust sample is obtained by means of a sampling nozzle. A dilution damper is located in the sampling take-off duct. Following the dilution damper a long straight section of duct is utilized to ensure an even profile of gases prior to entering the fabric filter. The gas enters the unit and is filtered by the outside bag type of filter, exhausted into the clean air plenum and from there it is ducted back into the precipitator inlet via its own fan. The collected dust is continuously fed from the hopper to a low pressure conveying system which conveys the dust into the precipitator.

2. Demonstration unit design characteristics - The filter is designed for 30,000 ACFM of process gas and has been operated at temperatures between 250-280°F. The filter bags are 16.4 feet long and 5 inches in diameter for a total cloth area per bag of 21.52 sq.ft. The unit consists of three separate compartments, each compartment capable of operating independently. Each compartment contains 64 bags for a total bag quantity for the filter of 192 and a corresponding total cloth area of 4,132 sq.ft. The filter is designed to run with air to cloth ratios between 3.5 and 7.2 ft/min.

B. Operation of the Demonstration Unit

The unit is temperature controlled utilizing dilution air dampers. This allows the filter test program to be run at predetermined temperature levels and thus carry out tests on fabrics that are temperature limited. The filter can be operated as either an on stream cleaning device or it can be operated as an off stream cleaning device with individual compartment isolation.

The cleaning is carried out by the Flakt concept of low pressure pulsing. With on stream cleaning the pulse pressure is less than 25 lbs. per square inch and the pressure drop across the tube sheet is held to less than 4 inches w.g. For off stream cleaning the pulse pressure is considerably lower due to the lower pressure requirements of this mode of operation.

TEST PROGRAM

To evaluate the high ratio concept on pulverized coal fired boilers the bags, cages and their interdependency were studied to determine the optimum combination. Filter bags were evaluated for filter resistance, i.e. pressure drop over filter media per unit of filtering velocity and for wear due to mechanical and chemical attack. The cage and bag combinations were evaluated as to wear characteristics.

The fabrics tested included acrylic felt and fiberglass weave using different designs of cages. Each fabric would be installed in its own compartment and each compartment could be run and recorded separately from the other compartments.

The filter unit is fully automated so that field supervision is held to a minimum. By operating this fabric filter for an extended period of time as a module of a full scale unit under actual operating conditions, substantial operating experience was obtained regarding boiler-fabric filter relationships. Continuous recording was carried out for all modes of boiler and fabric filter operation.

The following testing programs were instituted for each fabric material tested.

Fabric Resistance Test

A test which examines the pressure drop profile for a compartment over a set period of time after a full cleaning cycle of the compartment has been completed.

1. Evaluated after full load conditions after start-up.
2. One evaluation per week for two months after start-up.
3. Additonal test schedules if required during various conditions of boiler operation.

Filter Wear

Two bags from each compartment were removed for laboratory testing for both mechanical wear and chemical attack after two weeks, four weeks, eight weeks and continually in this manner until the end of the test. All removed filter bags would be replaced with identical bags.

Penetration Test or Seepage Test

1. After one week under full load, taken at the inlet and outlet of the fabric filter to obtain initial filter loading data.
2. At two to three week intervals until the end of the test.

It is well established that the emissions from a filter element peak immediately after cleaning. The momentarily high emission soon levels out to a low stable value, and the result from an emission test with an extended sampling time represents a value averaged over time and filter sections. This is especially the case for pulse cleaned filters with cleaning being efficient as well as frequent. While these tests were conducted for penetration during cleaning of the filter, opacity measurements were being recorded to study the effect of the emission levels and their duration.

FULL SCALE INSTALLATIONS

A typical design of a high-ratio filter for a Utility application is shown in Figure 7. Similar to the low ratio design, the high ratio filter is divided into a number of compartments with a common inlet and common outlet plenum. Bag cleaning is carried out with all compartments in operation. Each compartment has its own inlet and outlet shut off damper for sealing a compartment during inspection and maintenance.

SERVICE AND MAINTENANCE

Bag Maintenance Low Ratio and High Ratio

Bag maintenance on a fabric filter involves first a notification of failure by the alarm system. This is followed up by determining which filter compartment has the failed bag. To this point the low ratio and the high ratio units are similar however, from this point on the procedure differs greatly. With the low ratio unit, the compartment is isolated and then ventilated for a period of time to reduce the temperature and the gas concentration to an acceptable working level.

This operation can require a considerable amount of time. It is very probable that after this time the atmosphere in the compartment would require a life support system for the maintenance personnel. The maintenance personnel must then enter the compartment, locate and tie off the bag which has failed and exit from the chamber without causing damage to adjacent bags. The filter chamber can then be put back on line.

The high ratio design only requires that the designated compartment be isolated by shutting off the isolation dampers. The access roof panel of the compartment is removed using the overhead crane. The failed bag can then be capped by a maintenance person operating in a clean environment. After capping the defective bag, the roof panel is replaced and the unit put back on-line without maintenance personnel having entered the filter proper. The act of sealing off a failed bag has been converted from a chore which can require many hours of work in what can be a hazardous atmosphere to a straightforward procedure carried out in a clean and safe environment.

Bag Replacement Procedures - Low Ratio and High Ratio

Bag replacement costs are a significant factor when evaluating the life time costs of a fabric filter. The total cost is a function of bag material costs, replacement labour costs, the frequency of bag failure, and the quantity of bags.

The procedures for bag replacement clearly indicate one of the substantial benefits of the high ratio outside bag filter.

In order to accommodate bag replacement procedures on a low ratio unit, it is necessary to first design the individual compartments so that they can in fact become maintenance areas. This requires that the walls between compartments be insulated and the compartment must be capable of being ventilated to become a working area. The overall plant must also be designed with sufficient additional compartments to accommodate the reduced filter capacity during bag replacement.

For bag replacement on a high ratio unit, there are two basic design concepts. The first, which is an individual bag replacement operation with the compartment out of service. This requires a similar arrangement to the low ratio unit whereby an additional compartment is required to accommodate the reduced filter capacity during bag replacement. This option does not require that the personnel enter the compartment as is the case with the low ratio filter. There is also a cassette system as shown in Figure 8 where the compartment top is lifted up and the complete cartridge removed and transported directly to the bag replacement shop by use of an overhead crane system. A replacement cartridge with new bags is ready close by and replacement can thus be carried out in a matter of minutes.(Figure 9) The filter does not require additional compartments for reduced capacity during the bag replacement operation. The replacement shop which can be incorporated in the overall bag filter structure is a safe clean environemnt in which the maintenance crew can work on bag replacement as a normal maintenance operation. Bag replacement is therefore, a routine maintenance item which can be scheduled for normal shift operation.

RELIABILITY

The Utility Industry, as does many others, demands a high level of reliability from pollution control equipment. The high ratio pulse clean fabric filter has been successfully applied to a number of industries where reliability is of utmost importance. Flakt experience extends to the following industries with gas volumes ranging from a few thousand CFM to 4,000,000 CFM.

Industry	Typical Dust Characteristics
Aluminum Industry	Highly abrasive dust with a mean particle size 50-70 microns
Ferro-Alloy Industry	Ferro silicon with mean particle size 0.2 microns
Steel Industry	Iron oxide from BOF furnace with mean particle size 2-3 microns

Utility Industry	Flyash with mean particle size 20 microns

CONCLUSION

Based on experience in a number of industries with pulse type filters and extensive experience with full size demonstration units on coal-fired utility boilers, it is evident that the Utility Industry has available to it the technology and the experience necessary to apply high ratio pulse jet fabric filters to the collection of fly-ash.

ACKNOWLEDGMENT

The authors wish to acknowledge and express appreciation for the assistance of many individuals from within the Flakt Group.

fig1

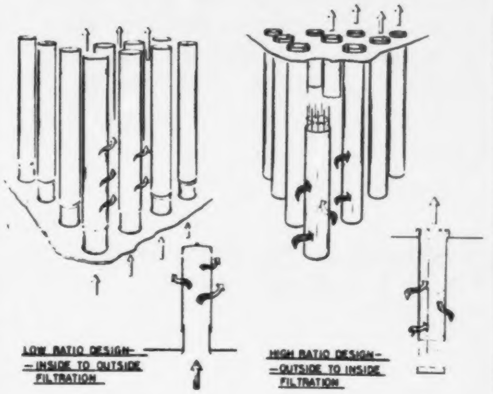
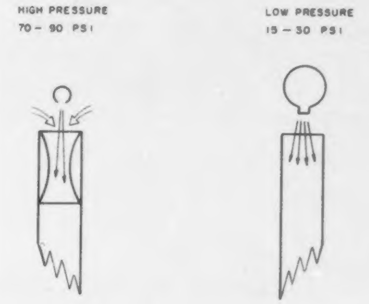

LOW RATIO DESIGN-
-INSIDE TO OUTSIDE FILTRATION
HIGH RATIO DESIGN-
-OUTSIDE TO INSIDE FILTRATION

fig2

PULSE CLEANING PRINCIPLE


HIGH PRESSURE
70 - 90 PSI
LOW PRESSURE
15 - 30 PSI

EJECTED PULSE

SECONDARY AIR 6 - 7 TIMES LARGER THAN PRIMARY AIR FLOW

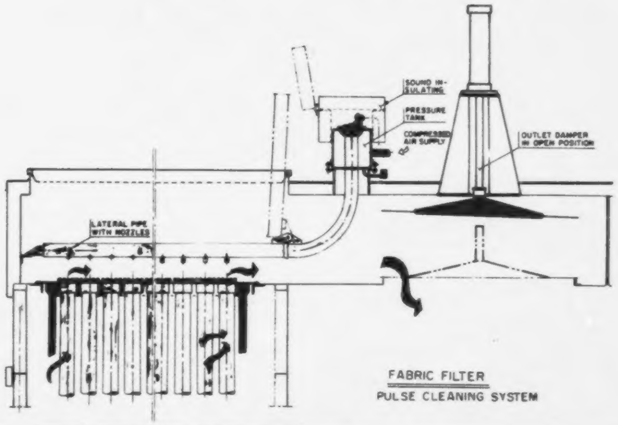
- SLOW PULSE
- SHORT BAG LENGTH

DIRECT PULSE

PRIMARY AIR EXPANDS DIRECT INTO THE FILTER MEDIA - ONLY 1 - 2 TIMES THE PRIMARY AIR EJECTED

- SHORT AND QUICK PULSE
- "DEEP" PULSE ≡ LONGER BAG LENGTH

fig3


SOUND INSULATING
PRESSURE TANK
COMPRESSED AIR SUPPLY
OUTLET DAMPER IN OPEN POSITION
LATERAL PIPE WITH NOZZLES

FABRIC FILTER

PULSE CLEANING SYSTEM

fig4

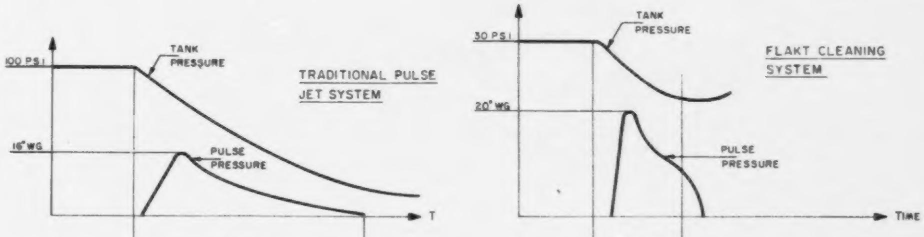


fig 5

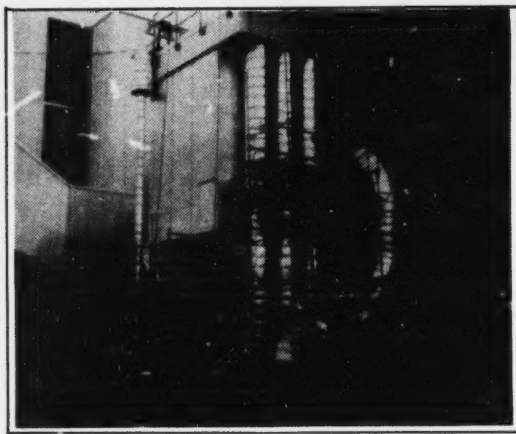
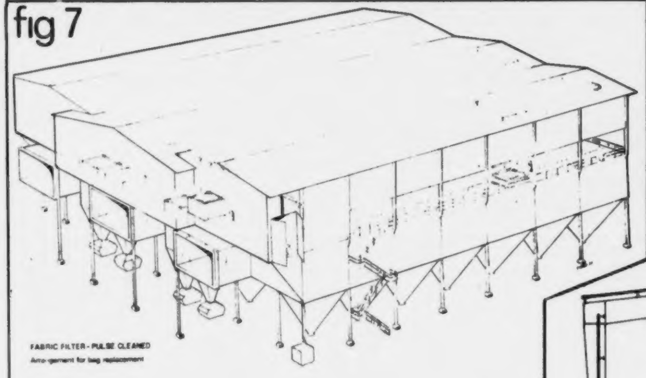


fig 6 *Typical coal and fly-ash properties*

Coal	
Moisture	19
Ash	16
Volatile	25
Fixed C	40
BTU	7870
Sulphur	0.15
Flyash	
P_2O_5	0.25
CaO	13.07
NA_2O	2.26
K_2O	1.00
SO_3	0.41
Fe_2O_3	4.64
LiO_2	0.01
MgO	0.97
SiO_2	50.38
Al_2O_3	26.10
TiO_2	0.91
UNDET.	0.00
Total	100.00

Average Maximum Resistivity (Ωcm) 5×10^{11} as measured by laboratory instruments at dew point 45°C.

fig 7



FABRIC FILTER - PULSE CLEANED

Arrangement for bag replacement

fig 8

FABRIC FILTER – **PULSE CLEANING**

PRINCIPAL CROSS SECTION

FLY ASH FILTRATION – ON STEAM CLEANING

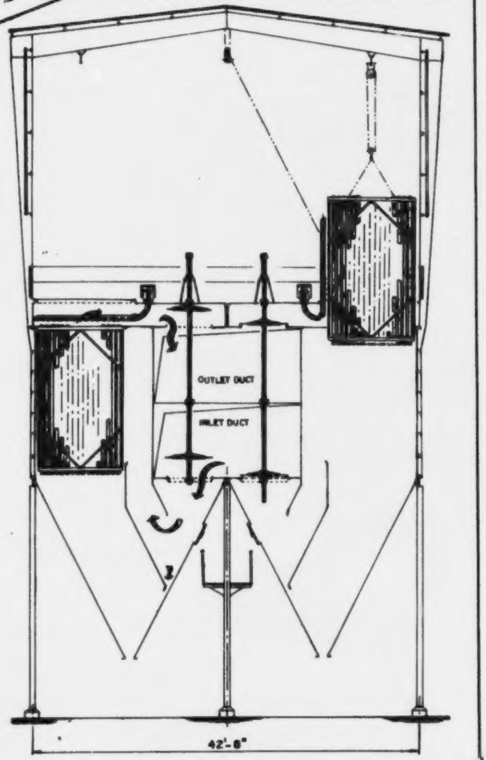
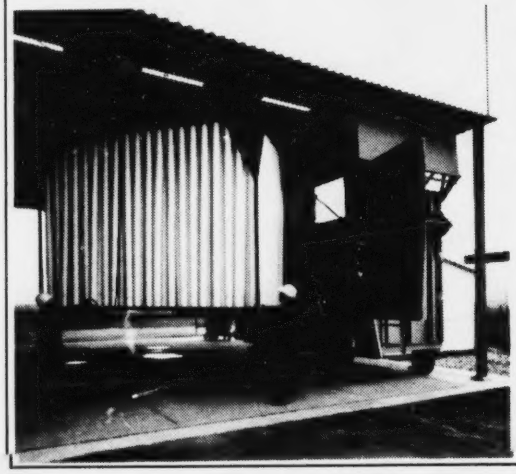


fig 9



RETRO-FITTING BAGHOUSES ON COAL-FIRED BOILERS

A CASE STUDY

J. Michael Osborne
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3M Company
St. Paul, Minnesota 55133

ABSTRACT

In 1977, 3M signed a stipulation agreement with the Minnesota Pollution Control Agency, agreeing to install baghouses on the two traveling grate, coal-fired boilers, at its Chemolite, Minnesota, plant. The baghouses have been designed, bids accepted, and purchase agreement signed with Industrial Clean Air to furnish reverse air baghouses. The installed cost of the baghouses will be in excess of $2,000,000 to filter 70,000 acfm.

Currently, air pollution control of the boilers' emissions is provided by multiclones. During the last six years, 3M engineering and operating personnel were able to improve the boilers' performances to the point that they could meet the 0.4 pounds per million BTU's particulate emission regulation but an occasional opacity problem persisted. The improvement in performance was achieved by baseloading the two units, continuously withdrawing fly ash from the multiclone hoppers, adding over-fire air to one of the boilers, improving coal handling to minimize size segregation, and writing stricter coal specifications.

A comparison will be made between the installed costs of the two systems and their particulate removal effectiveness.

INTRODUCTION

Anytime the word retro-fitting comes to mind, I think of a forced fit, a makeshift arrangement that optimizes a bad situation. It tends to be expensive and complicated. With current environmental regulations, similar retro-fits are a fact of life for existing facilities (whether coal-fired boilers or production equipment) which are unable to comply with the established emission limits.

This presentation is a summary of 3M Company's experiences to date with retro-fitting baghouses on two coal-fired boilers at its Chemolite plant in Minnesota. Table 1 contains a detailed description of the two coal-fired boilers. Their combined steam capacity is 125,000 pounds per hour.

BACKGROUND

Over the past nine years, 3M has had an almost continuous program to improve the performance of the coal-fired boilers at Chemolite. Table 2 is a list of the projects and the total dollars spent up to and including the current baghouses. The boiler plant was constructed in the late 1940's and by 1970 consisted of three travelling grate, coal-fired units equipped with multiclones.

In December, 1972, 3M entered into a stipulation agreement with the Minnesota Pollution Control Agency (MPCA) to convert the coal-fired boilers to oil-gas firing. With the coming of the oil embargo and after replacing Boiler Number 1, the conversion program was terminated. Plans and specifications for the conversion of the other two boilers were almost complete at the time the project was stopped. The MPCA was informed in writing and a new program was instituted to upgrade the performance and reduce the emissions of the two remaining coal-fired boilers.

All aspects of the boiler's operation were reviewed, discussed, and evaluated. The new oil-gas boiler allowed the coal-fired units to be base-loaded. Rewriting of the coal specifications and changes in coal handling minimized the amount of fines and segregation. A new fly ash storage tank and piping changes allowed for continuous fly ash withdrawal from the Boiler Number 2 multiclone ash hoppers. An annunciator panel was installed to monitor the fly ash hopper levels and the feedwater pressure. The stokers were modified with the addition of stainless steel wear plates and over-fire air was added to Boiler Number 2. With these improvements test results, as shown in Table 3, demonstrated that we could meet the state regulation of 0.4 pounds particulates per MM BTU's for existing boilers.

TABLE 1

CHEMOLITE, MINNESOTA, MFG. PLANT

COAL-FIRED BOILER SPECIFICATIONS

	MANUFACTURER	BOILER TYPES	CONTROL EQUIPMENT SPECIFICATIONS
Boiler No. 2	Bros-Cross Drum Type	Detroit Grate Stoker Rated Steam Capacity: 50,000 Pounds Per Hour Design Pressure: 260 PSIG	Bank of 6" Multi-Clones
Boiler No. 3	Erie City Cross Drum Type With Air Pre-Heater	Detroit Grate Stoker Rated Steam Capacity: 75,000 Pounds Per Hour Design Pressure: 275 PSIG	Bank of 9" Multi-Clones

TABLE 2

CHEMOLITE BOILER PROJECTS

New #1 Boiler
Boiler Improvements
Replace Boiler No. 2 Study
Stoker Modifications
Improved Feedwater System
Overfire Air - Boiler No. 2
Sampling Ports & Platform
Fly Ash Level Indicators
Annunciator Panel
Emission Testing
Baghouses

TOTAL COST >$3.1 Million

TABLE 3

PARTICULATE EMISSION TEST RESULTS

PARAMETER	BOILER NO. 2	BOILER NO. 3
SCFM	16,100	24,100
% Isokinetic	98	100.4
MM BTU's/Hr	57	82
GR/SCF	.076	0.1
#/MM BTU's	0.18	.25
# Steam/Hr	40,000	74,000

During the negotiation of a new stipulation agreement in 1977, a decision was made to install baghouses. While 3M engineering and operating departments were confident of meeting the particulate emission limit, it was felt that a rigorously enforced opacity limitation would be impossible to meet. The MPCA regulation on opacity for existing facilities reads as follows:

> " . . . no owner or operator . . . shall cause to be discharged . . . any gases which exhibit greater than 20% opacity, except that a maximum of 60% opacity shall be permissible for four minutes in any 60 minute period and that a maximum of 40% opacity shall be permissible for four additional minutes in any 60 minute period."

The decision to install baghouses rather than alternative control equipment was based upon the following reasons:

1. Cost estimates and space requirements for baghouses and electrostatic precipitators were not significantly different. Additionally, precipitator efficiency is relatively poor when burning low sulfur coal as we do at Chemolite to meet SO_2 emission control regulations.

2. Wet collectors were more expensive both to construct and operate.

3. Baghouses are better able to control opacity and were considered best available control technology.

Other factors which also were considered included:

1. Coal is purchased on a yearly basis and therefore the supplier and/or coal mine could also change yearly, potentially affecting the performance of an electrostatic precipitator.

2. The possibility of burning dry scrap in the boilers was being investigated. A baghouse would be better able to handle the variation in particulate emissions.

DESIGN OF THE BAGHOUSE INSTALLATION

For maximum operation flexibility, the baghouses ductwork was designed to allow a return to existing operation should a problem develop with the new baghouses. Separate baghouses were sized and designed for each boiler to increase system reliability. A push-pull fan system was determined to offer the most flexibility and reliability plus, by utilizing the existing fans, it was estimated to be more economical. Poppet valves were selected to guarantee tight closure of each baghouse module. A slight leakage of hot boiler exhaust into a shutdown module could lead to acid condensation problems and bag deterioration.

Reverse air and pulse-jet baghouse suppliers were asked to bid. To allow cost comparisons on somewhat equivalent bases, maximum air-to-cloth ratios for each type and the filter bag material were specified.

Industrial Clean Air (ICA) reverse air baghouses were selected after carefully evaluating each bid and determining that for this application their baghouses provided the best value at the lowest price. Table 4 contains the general specifications of the ICA baghouses currently being fabricated for installation at Chemolite. Figure 1 is the schedule for the project indicating a 2½ year period between start of engineering design and operation of the facility. Figure 2 is a simplified layout showing the location and size of the baghouses and some of the site constraints that usually complicate retro-fits, such as the water tower and the existing, large brick stack.

Once the baghouses are installed and operational, particulate emissions from the coal-fired boilers will be less than one pound per hour and opacity will essentially be zero.

THE COST

It is estimated that the installed cost of the facility will be $2,100,000. An approximate breakdown is contained in Table 5. The cost is almost $30 per ACFM. Another way of looking at it is presented in Figure 3. The multiclones remove 265 pounds per hour of fly ash while the new baghouses will remove an additional 53 pounds per hour. Therefore, the multiclones provide approximately 85% control for a cost of approximately $0.03 per pound of particulate controlled. Control of the additional 14-15% of emission costs three orders of magnitude more per pound of particulate removed!

CONCLUSIONS

By the end of 1979, 3M will have spent over three million dollars and over twenty thousand engineering hours on pollution control for the Chemolite coal-fired boilers. Although the technology now exists for ultra-high efficiency particulate control and visible emissions elimination from coal-fired industrial boilers, the costs are extreme and the benefits questionable. The dollars spent on design, construction, and operation of the baghouses do not appear to have a reasonable cost/ environmental benefit.

TABLE 4

GENERAL SPECIFICATIONS

REVERSE AIR BAGHOUSES

	BOILER NO. 2	BOILER NO. 3
Volume (ACFM)	28,900	44,600
Temperature (^{o}F)	350	350
Air-To-Cloth Ratio(FPM)		
Gross	1.2	1.49
Net	2.11	2.23
No. of Compartments	4	5
Filter Area/Compartments(SF)	6,000	6,000
No. of Filter Bags/ Compartment	120	120
Reverse Air Fan (HP)	40	40
(ACFM)	9,000	9,000
Baghouse Dimensions		
Length	40'	50'
Width	12'	12'
Height	50'	50'
Overall	50' x 40' x 50'	

TABLE 5

CHEMOLITE BAGHOUSES

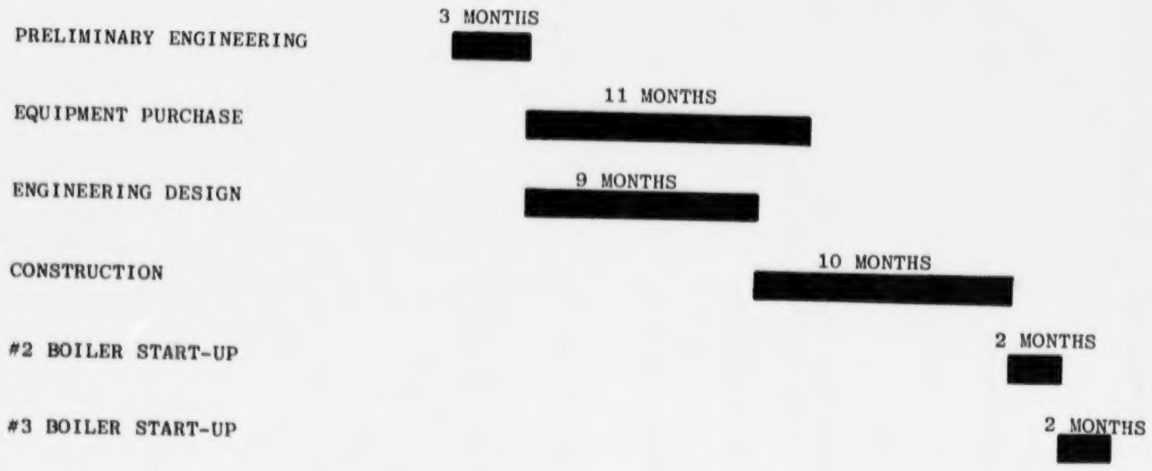
APPROXIMATE INSTALLED COST BREAKDOWN

Economizer	$ 150,000
Ash Handling Eqpt.	50,000
Fans	50,000
Ducting, Insulation and Instrumentation	950,000
Two Baghouses	950,000
TOTAL COST	$2,100,000
Facilities	$1,790,000
Engineering	$ 310,000

FIGURE 1

CHEMOLITE BOILER FACILITY

BAGHOUSE INSTALLATION SCHEDULE



TOTAL PROJECT CALENDAR TIME = 26 MONTHS

FIGURE 2

CHEMOLITE BOILER FACILITY

SIMPLIFIED LOCATION DRAWING

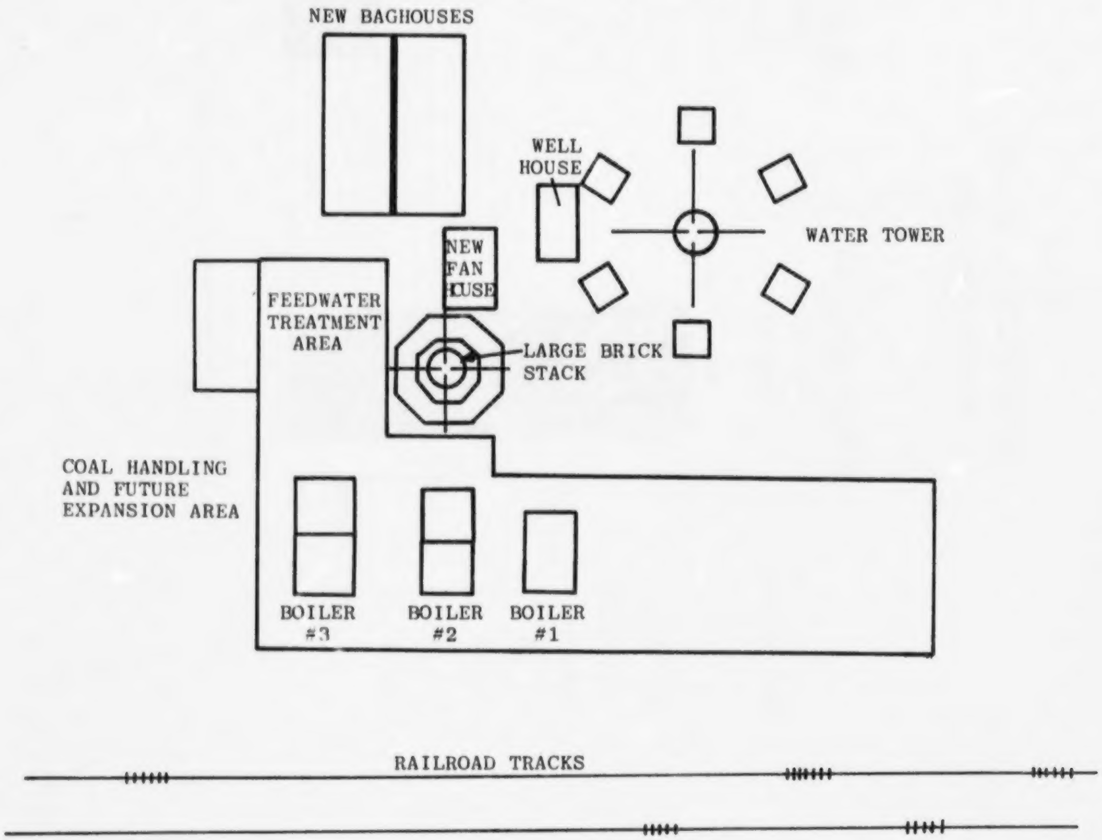
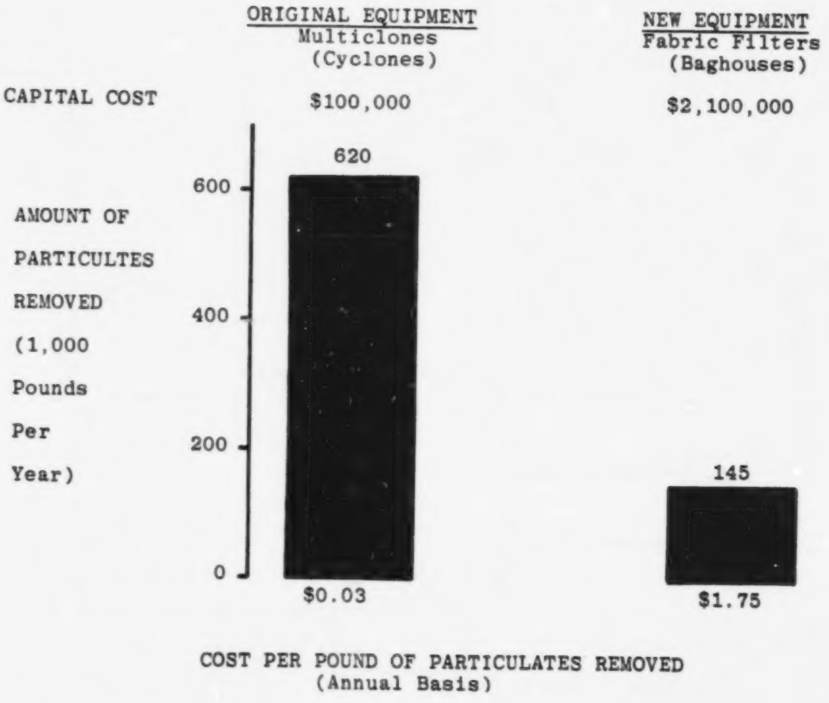

NEW BAGHOUSES
WELL HOUSE
WATER TOWER
NEW FAN HOUSE
FEEDWATER TREATMENT AREA
LARGE BRICK STACK
COAL HANDLING AND FUTURE EXPANSION AREA
BOILER #3
BOILER #2
BOILER #1
RAILROAD TRACKS

FIGURE 3

CHEMOLITE BOILER FACILITY

APC COST COMPARISON



Stringent particulate emission regulations were and are being met with the existing cyclone air pollution control system. The opacity requirements were exceeded only for very brief periods once or twice per week. The amount of additional control cost necessary to comply with strict interpretation and enforcement of a qualitative opacity problem suggest that there are far better ways to spend environmental control dollars.

By presentation of this case history we have shown the complexity and cost for retro-fitting baghouse particulate control technology on two industrial coal-fired boilers. Due to the extreme costs and questionable benefit, the transfer and utilization of this technology would be recommended only if a definitive pollution problem existed for other similar operations.

MATCHING A BAGHOUSE TO A FOSSIL FUEL FIRED BOILER.

David W. Rolschau, Pres.
DaVair, Inc.
1161 Cedar View Drive,
Minneapolis, Minnesota 55405

The baghouse is becoming the preferred solution for stack clean-up of fossil fuel fired boilers. It has long been recognized as the device which produces the best effluent gas quality; its operation is equally reliable with fuel from any source; and recent work indicates that a baghouse is an efficient, low cost remover of SO_2 when injected with appropiate chemicals.

In order to gain maximum benefit from the advantages of a baghouse installation, the designer must properly anticipate certain system operating characteristics which may affect total performance.

Cyclic Drag Variation.

A boiler-baghouse installation is often breeched in series as shown in Figure 1. Many large installations installed as shown have operated satisfactorily, but small installations have not. Many small installations suffer poor boiler combustion control, caused by a baghouse characteristic known as cyclic drag varation.

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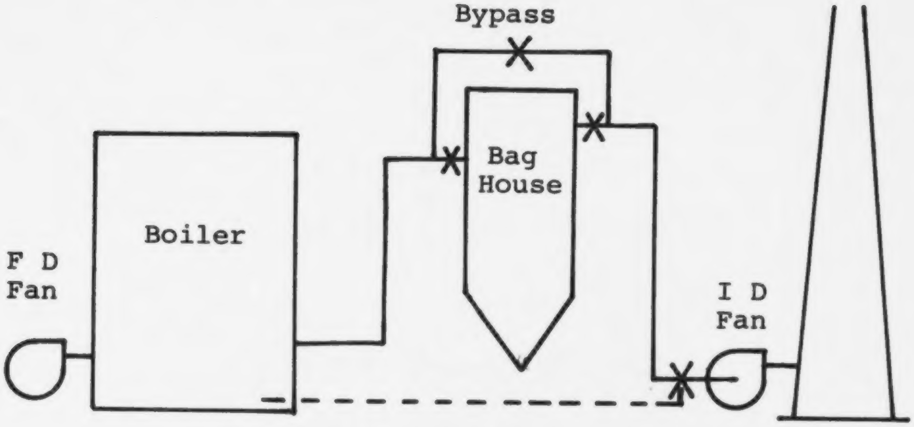

Figure 1.

SERIES BREECHED BOILER BAGHOUSE

The boiler forced draft fan in Figure 1 is regulated by combustion controls to provide the proper amount of air for efficient combustion. The induced draft fan is pressure regulated to create a slight draft in the furnace. A problem may be created in the furnace when a baghouse is placed in the system, because the pressure drag across the baghouse is not constant, but varies with time, as shown in Figure 2.

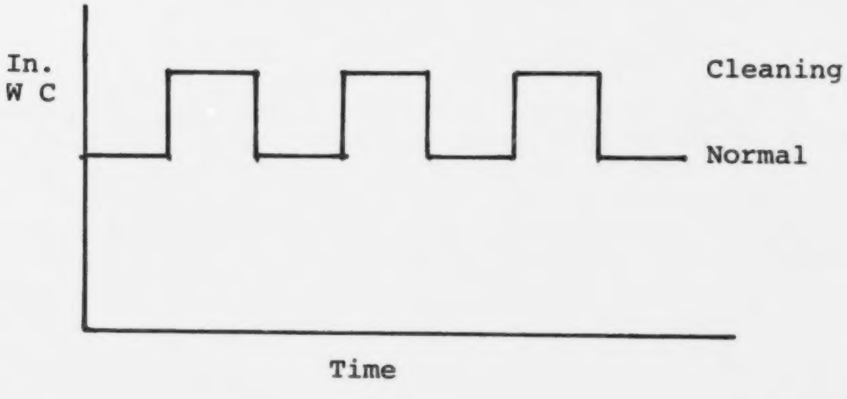

Figure 2

Filter Drag vs. Time.

In a typical small installation with 40,000 ACFM gas flow, a zero reverse gas four cleaning sector baghouse might have 4 in. W. C. drag during normal cycle, and 6 in. W. C. drag when one sector was taken out of service during cleaning cycle. The magnitude of drag variation depends upon the number of cleaning sectors provided, and upon the presence or absence of cleaning gas in the cleaning cycle. A curve showing the effects of reverse gas and the number of cleaning sectors is presented in Figure 3. This curve is derived from the fact that N-1 sectors are available during cleaning cycle, and the assumption that pressure drag varies as sector ACFM raised to the 1.5 power.

The designer should note that decreasing the number of sectors often lowers the baghouse cost and complicates the induced draft fan control problem.

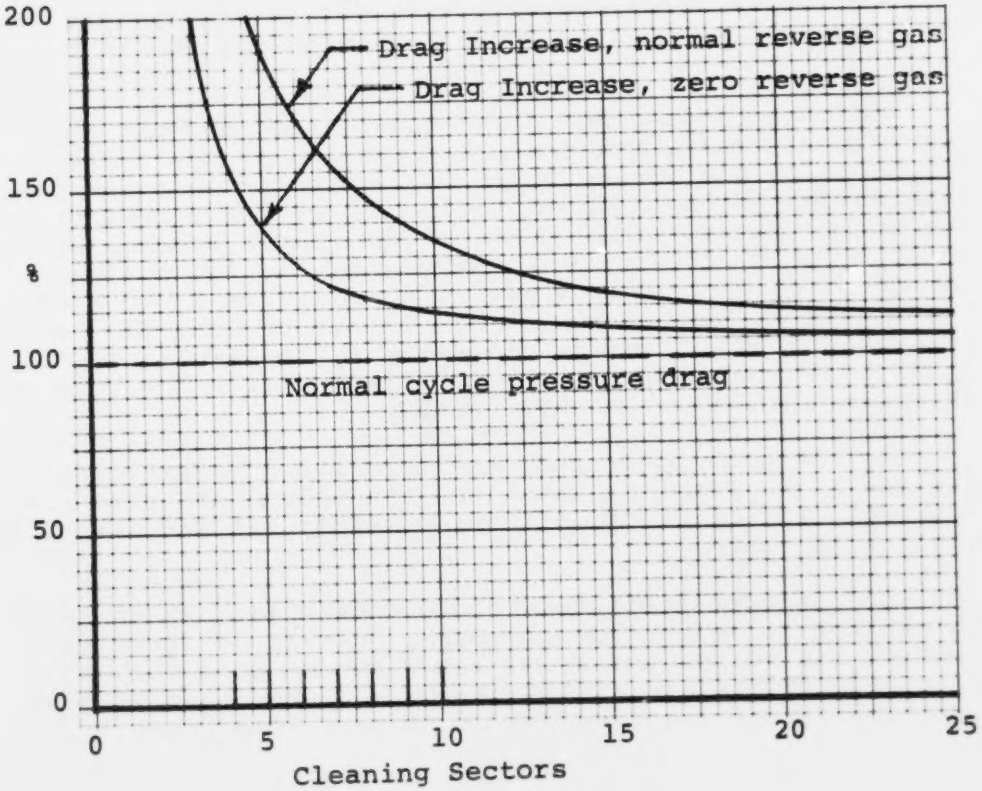

Figure 3

Drag Variation

The baghouse cleaning cycle drag variation shown in Figure 3 upsets the furnace draft and the combustion gas volume handled by the fan system. Figure 4 depicts the induced draft and forced draft fan system on a plus-minus coordinate system with the x-x axis representing interstage (furnace) pressure.

The system resistance curves, A and B, for induced draft and forced draft are both plotted. Note that two system curves, A_c and A_n, are required for the induced draft fan because the baghouse has a different pressure drag for both its cleaning and its normal cycle. The induced draft system resistance curves are based on one hundred per cent flow with a 2 in. W. C. boiler draft, a 4 in. W. C. filter drag in normal cycle, and a 6 in. W. C. filter drag during cleaning cycle. The forced draft system resistance curve is based on a 2 in. W. C. drag.

The fan curves for the induced draft and forced draft systems are plotted as Curves C. and D. The induced draft fan controller opens and closes as the filter cycles, causing the induced draft fan to operate alternately on Curve C_c or C_n.

Starting from point E and taking into account the reaction of the forced draft fan system, as the filter cycles from E to F, the forced draft fan, which tries to handle the same volume as the induced draft fan, cycles from G to H. The volume change stops short of the volume associated with point F due to the inter-dependence of the two systems. To locate point H, find a volume between points E and F where the length of line JK equals the length of line HI. At this volume, the pressure developed by the two fans, HJ, is equal to the combined system resistance, IK. The rise in interstage pressure is equal to HI.

In the case presented, the interstage pressure raises 0.5 in. W. C. from setpoint, and the volume drops to ninty four per cent of designed flow, possibly filling the boiler house with smoke.

The induced draft fan volume controller, which responds to variations in furnace pressure, must be designed to control the volume swings of the induced draft fan and react within the cycle time of the baghouse, and it must function at any required degree of part load capacity.

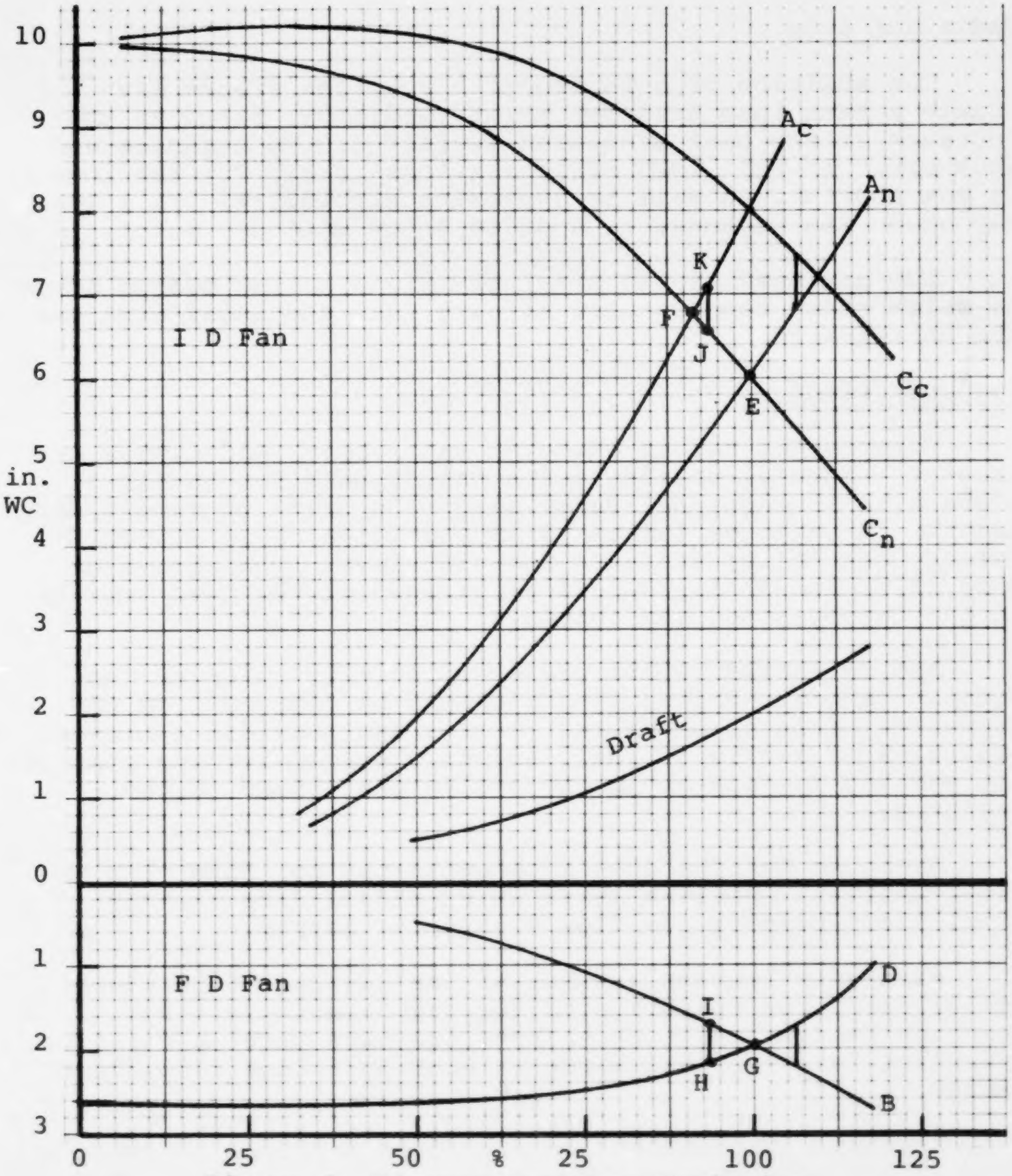

Figure 4, Furnace Pressure Variation.

The drag variation problem exists in all boiler baghouse installations. The problem becomes more critical on installations of 100,000#/hr. of steam and smaller, when too few cleaning sectors are provided.

Our firm will not quote a baghouse with less than twenty cleaning sectors, regardless of the stack gas volume required.

Radiation Loss.

The addition of a baghouse to a boiler system may create a part load acid dew point condition, based on the increase in the heat radiation surface of the baghouse and ductwork. If full load radiation loss is 25° F., the loss at one fourth load will be approximately 100° F. This loss may cause the baghouse to operate below acid dew point.

The engineer should make provisions during design stage to raise stack temperatures if part load dew point problems are anticipated.

Baghouse Fires.

Fire danger exists whenever fuel, heat, and oxygen are present. Special consideration should be given to fire prevention in baghouse system design in order to reduce fire hazard. A baghouse functions in a critical fire situation during both boiler start-up and shut-down. The shut-down mode is particularily hazardous because of the heat inertia of the baghouse and its contents.

Ash collected in the baghouse normally contains combustile carbon. Collected ash should be removed from the hopper as often as possible. Stored ash provides a thermal heat sink, a source of fuel, and an elevated burning platform for burning the ash up in the active gas stream of the baghouse.

Baghouse designs should be evaluated for fire risk and survivability. Designs exist which reduce fire risk by eliminating primary gas flow within the hopper.

Fire often causes warpage of the baghouse tube sheet, making continued operation of the baghouse impractical. Baghouse designs exist which have low tube sheet L/d ratios, and which have survived fires without suffering tube sheet damage.

Baghouse instrumentation should be designed to sense a fire in any compartment through heat and/or opacity. The fire detection signal should initiate the opening of the bypass valve and the closing of the baghouse isolation valves so as to extinguish the fire by oxygen starvation. An orderly shut down procedure should then begin which will protect other equipment from damage. Bags should be considered expendable. The objective in fire control should be to prevent high temperature from damaging the baghouse structure.

An adequate design concept can limit fire loss to an acceptable level.

SO_2 Removal.

Liquid concentrate solutions of sodium, calcium, and potassium can be injected into a baghouse inlet to react with SO_2, causing SO_2 to form as a precipitate which can be filtered out of the gas stream as a dry sulphate mixed with fly ash. Solution water is evaporated in the hot gas stream and passes through the baghouse as a vapor. The principal advantage of this method is that the sulphate is collected as a dry material, thereby reducing both the volume and disposal problems of the sulphate. Our firm is currently evaluating patents which will use a baghouse to create dry, useful, marketable sulphur by-products.

We feel that the day has arrived when the cost of stack clean-up of both particulate and SO_2 can be fully offset by income from the by-products produced.

Conclusions.

The baghouse is the air quality device of the future. By properly understanding its limitations and capabilities, a designer can create a system which will economically burn fossil fuels in an environmentally acceptable manner.

START-UP, OPERATION AND PERFORMANCE TESTING
OF FABRIC FILTER SYSTEM
HARRINGTON STATION, UNIT #2

George Faulkner
Kenneth L. Ladd
Southwestern Public Service Company
Amarillo, Texas

INTRODUCTION

Southwestern Public Service Company brought its Harrington Station, Unit #2, fabric filter system into service June 21, 1978. Because the system has only been on-line a few weeks, performance data is limited; therefore, the objective of this paper will be to review the procedures which were implemented by Southwestern Public Service to assure a trouble-free start-up. It should be noted that the criteria applied at Harrington Station is only applicable to that installation, or one identical to it. Southwestern feels that additional operating experience and analyses must be obtained before general criteria for utility fabric filter systems can be formulated.

I. DESCRIPTION OF THE SYSTEM

Unit #2, on which the fabric filter system is installed, is a 350 MW tangentially-fired steam generator. The boiler utilizes pulverized low sulfur Western coal to produce 2,688,000 lbs/hour of steam (the average characteristics of Western coal are 8425 Btu/lb, 0.3% sulfur and 5.5% ash). The fly ash laden flue gas from the boiler flows through the preheater directly through the fabric filter system and then out the stack (Figure 1).

Fabric Filter System

The emission control device selected for Unit #2 is a Wheelabrator-Frye Inc. fabric filter (baghouse) system. The baghouse is designed to

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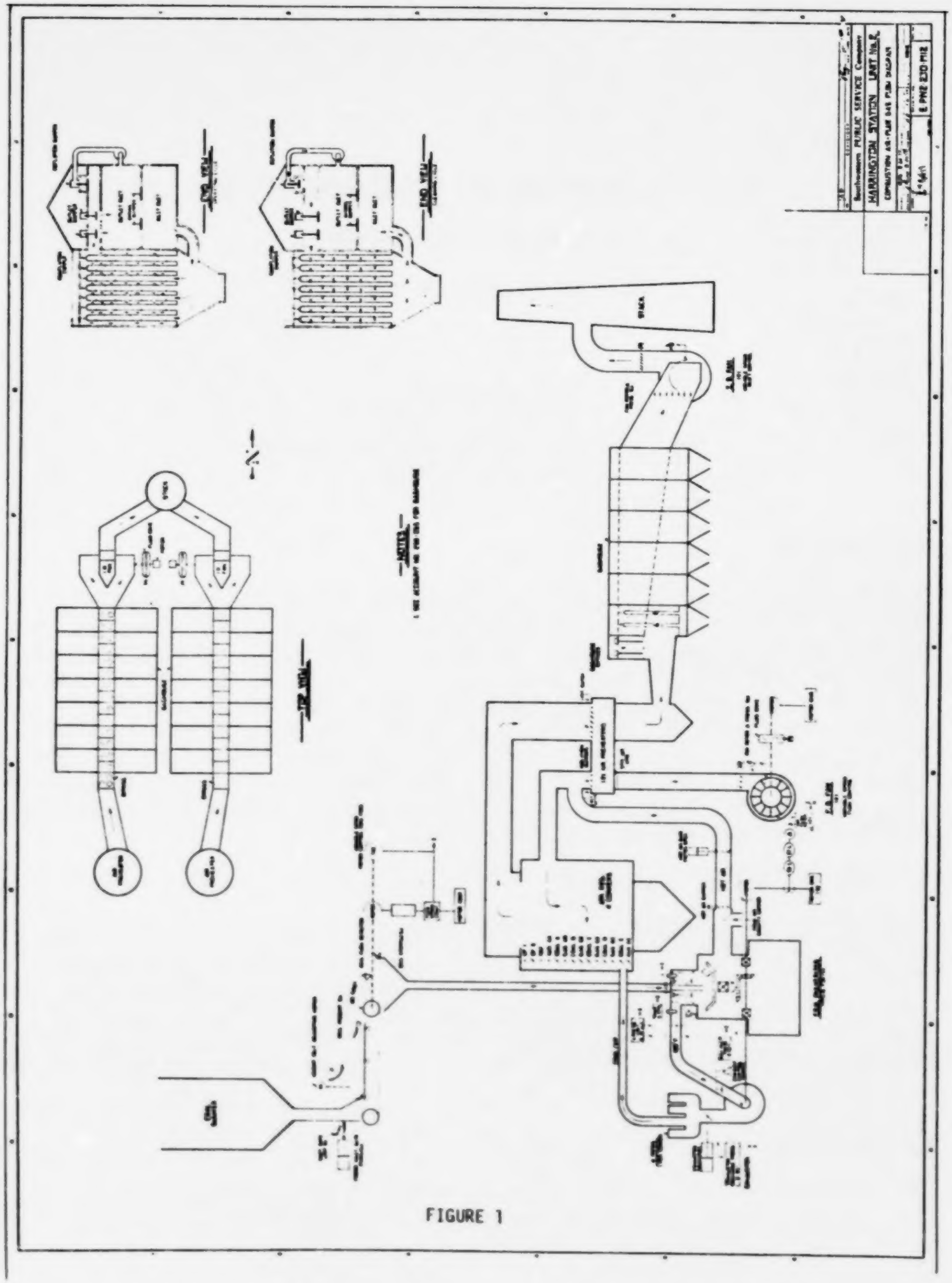

TOP VIEW
END VIEW
END VIEW
STACK
NOTES
Southwestern PUBLIC SERVICE Company
HARRINGTON STATION UNIT No. 2
COMBUSTION AIR-FLUE GAS FLOW DIAGRAM
E PHE 230 M12

FIGURE 1

operate at a flue gas flow of 1,650,000 acfm at 313° F. Minimum design efficiency is 98.6%, which would permit 0.1 pounds of particulate/million Btu out the stack. The exterior of the baghouse has 3.5" of fiberglass insulation. There is no insulation between plenums and compartments. The baghouse is divided into 28 compartments, each containing 204 filter Dustubes that are 11.5" in diameter and over 366" long (see Table 1 for bag characteristics):

Table 1. FABRIC CHARACTERISTICS

Maximum Operating Temperature	550° F (288° C)
Thread Count	66 x 30
Weight	10.5 oz/sq. yd.
Permeability at 0.5 WG	45-65 cfm/ft^2
Finish	Silicon/Graphite

Air-to-cloth ratios are as follows:

Gross air-to-cloth ratio:	3.16:1
w/1 compartment out of service	3.27:1
w/2 compartments out of service	3.40:1

The baghouse is provided with bypass dampers for start-up, emergency operation, and shutdown. There are two baghouses on Harrington Station, one designated East baghouse, and the other designated West baghouse. Each one has its own operating control system and all bypass dampers are separate for each system. There are four motor-operated bypass dampers per baghouse. These are poppet type dampers and are 68" in diameter; they can be operated independently of each other. For each compartment there are the following dampers: (1) outlet, poppet type, 70" diameter, motor operated; (2) reinflation, poppet type, 12" diameter, motor operated; (3) deflation, poppet type, 30" diameter, motor operated; and (4) inlet, butterfly type, 60" diameter, manually operated.

Normal Filtering and Cleaning Sequence

During normal filtering sequence, outlet and reinflation dampers are open and the deflation damper is closed. During cleaning cycles the reinflation and outlet dampers close, leaving only the inlet damper open. After an initial 30-second settle period the deflation damper opens, which pressurizes the clean side of the bag. This pressure breaks up the filter cake collected on the dirty side of the bag.

After a second 30-second settle period the shaker motors are energized for 5 to 30 seconds in order to shake off the remaining filter cake. After a final 60-second settle period the reinflation and outlet dampers open, putting the compartment back into service.

Cleaning Cycle Modes

The Unit #2 fabric filter system has four cleaning cycle modes which were designed to provide maximum flexibility of operation. Mode 1 will clean the West baghouse only and then the control system will reset; Mode 2 will clean the East baghouse and reset; Mode 3 will clean compartments 1 through 28 before the system is reset; Mode 4 will clean the East and West sides simultaneously, one compartment at a time on each baghouse.

II. PRELIMINARY PLANNING FOR START-UP

Before a start-up plan was formulated for the Harrington Station baghouse, an investigation was made of other fabric filter system start-ups. Southwestern personnel visited with other utilities which have baghouses in operation, seeking the advice of start-up personnel at various locations, particularly at Kramer and Sunbury Stations. Individuals known to have expertise in the start-up of these systems, such as Rowan Perkins of DuPont and Fred Cox of Menardi Southern, were consulted. Additionally, a literature survey was made and the recommendations of various manufacturers were studied and discussed with Wheelabrator-Frye representatives.

After reviewing the information collected on other fabric filter system start-ups, a procedure plan was developed by Southwestern personnel. The plan utilized certain start-up principles outlined by Rowan Perkins in his paper titled "Considerations in Start-up Procedures for Fabric Filters on Coal-Fired Boilers."

Recommended Consideration:

Orient operators.

SPS Procedure:

Classroom sessions were held to orient operators on baghouse operation.

Recommended Consideration:

Check out equipment.

SPS Procedure:

All baghouse equipment was checked thoroughly before initial start-up. Baghouse was cycled several times to insure that the cleaning cycle operated as designed.

Recommended Consideration:

The philosophy of "keep it hot and keep it dry" should be adhered to.

SPS Procedure:

Inlet temperature of 300^{o} F was to be maintained; outlet temperature was to stay within a 20^{o} - 30^{o} F temperature drop. At no time during start-up was outlet temperature to be less than 280^{o}F.

An acid dew point was determined by duplicating the start-up conditions on Unit #1 and then measuring acid dew point with dew point meter. These conditions were 100% coal with only igniter gas in service. The highest dew point monitored under these conditions was 110° F which indicated that dew point problems would be minimal on the #2 unit start-up, especially if a 300° F inlet temperature was maintained.

Recommended Consideration:

Preheat compartments.

SPS Procedure:

Because a preheater was not designed into the baghouse, preheating of compartments is limited to energizing the hopper heaters (16 KW per hopper) several days before start-up in order to heat the fabric as much as possible. It was felt that by maintaining a 300° F inlet temperature a preheat system was not necessary.

Recommended Consideration:

Precoat bags.

SPS Procedure:

It was decided that since low sulfur coal would be utilized, coal ash would be used to condition the fabric in the actual start-up of the baghouse.

Recommended Consideration:

Start-up with cleanest fuel.

SPS Procedure:

Unit #2 has the capability to fire natural gas up to a load of 200 MW. Before starting the baghouse it was decided to minimize the natural gas burning and maximize coal firing at 200 MW. By starting up on natural gas, particulate emissions out the stack are minimized while the required inlet temperature is attained.

Recommended Consideration:

Start-up should be accomplished quickly.

SPS Procedure:

While maintaining temperature through the baghouse and while giving consideration to boiler draft, compartments were to be brought in service as rapidly as possible.

Recommended Consideration:

Designate specific sequence for compartments to be brought on-line.

SPS Procedure:

The sequence for compartments to be brought on-line was determined and adverse effects of start-up on boiler draft were to be minimized; and a procedure to slowly close bypass dampers as the baghouse was put into service was determined.

Recommended Consideration:

Add compartments as load increases.

SPS Procedure:

It was decided to bring into service an additional compartment for approximately every 10-11 MWs increase in load.

Recommended Consideration:

Monitor required parameters during start-up and clean bags after start-up.

SPS Procedure:

It was planned to initiate the cleaning cycle when ΔP reached 5" WG, and to monitor major parameters such as ΔP, stack opacity and inlet and outlet temperatures.

III. START-UP OF SYSTEM

Isolation of the System

Because Harrington #2 was capable of start-up on natural gas, the baghouse was bypassed for several weeks before it was started. During this phase all dampers were closed in order to completely isolate the baghouse and to prevent condensation of flue gas in the baghouse. Because no dampers are 100% leakproof, however, all compartment doors were left open in order to pull fresh dry air into the baghouse and to prevent any leakage of wet flue gas into the compartments.

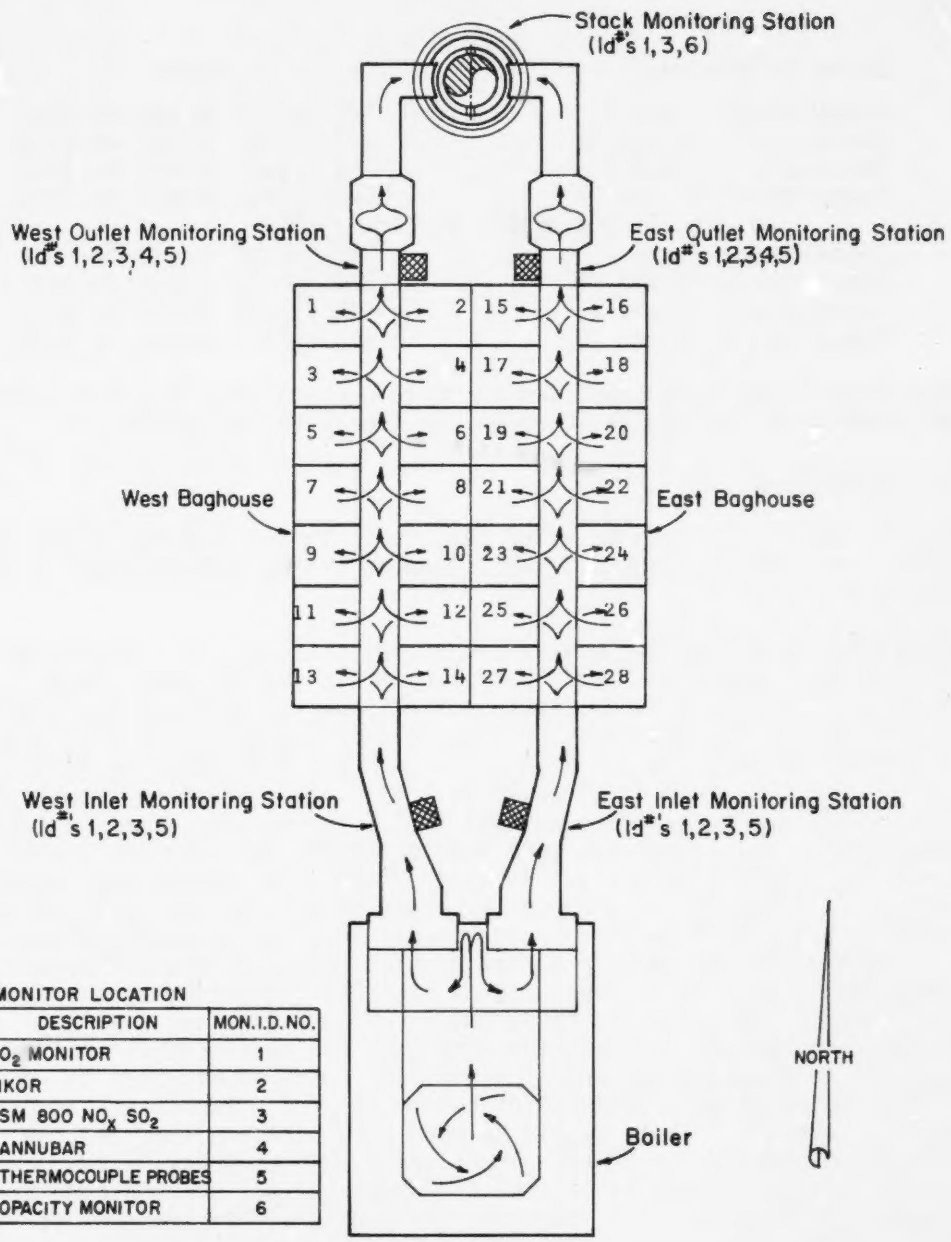
Preheating of the System

With all baghouse compartments still isolated from the flue gas, all hopper heaters were energized for two or three days prior to start-up in order to help preheat the compartments. Since the unit was on line but not firing coal, all bypass dampers were open and the unit had approximately 200 MW load on the boiler.

The planned start-up consisted of maintaining a consistent 200 MW load, increasing coal flow and decreasing natural gas flow to the boiler; a minimum condition of at least 50% coal firing was desired. Once the air preheater gas-out temperature was at least 300^{0} F on the East and West side, the baghouse was ready for start-up.

Planned Start-up

It was planned to bring two compartments on line at a time until half of them were in service, because the unit would be at half load (see Figure 2). The following procedure was selected:


Stack Monitoring Station
(Id#'s 1,3,6)
West Outlet Monitoring Station
(Id#'s 1,2,3,4,5)
East Outlet Monitoring Station
(Id#'s 1,2,3,4,5)
1
2
15
16
3
4
17
18
5
6
19
20
7
8
21
22
9
10
23
24
11
12
25
26
13
14
27
28
West Baghouse
East Baghouse
West Inlet Monitoring Station
(Id#'s 1,2,3,5)
East Inlet Monitoring Station
(Id#'s 1,2,3,5)
NORTH
Boiler

MONITOR LOCATION

QUAN.	DESCRIPTION	MON. I.D. NO.
5	O_2 MONITOR	1
4	IKOR	2
5	SM 800 NO_x SO_2	3
2	ANNUBAR	4
8	THERMOCOUPLE PROBES	5
1	OPACITY MONITOR	6

FIGURE 2

REVISIONS

HARRINGTON Nº2 FLUE GAS MONITORING STATION

Southwestern *PUBLIC SERVICE* Company

DRAWN	DATE	CHECKED	APPROVED	SCALE	SYSTEM ENGINEERING DEPT.	REV.
TLC	4/3/78			N.T.S.	NO. 7804030AE	

Bring in Service:	Close:
Compartments 1 and 3	1st bypass damper on West
Compartments 16 and 18	1st bypass damper on East
Compartments 5 and 7	2nd bypass damper on West
Compartments 20 and 22	2nd bypass damper on East
Begin closing bypass dampers slowly	
Compartments 9 and 11	3rd bypass damper on West
Compartments 24 and 26	3rd bypass damper on East
Compartments 13 and 2	4th bypass damper on West
Compartments 28 and 15	4th bypass damper on East

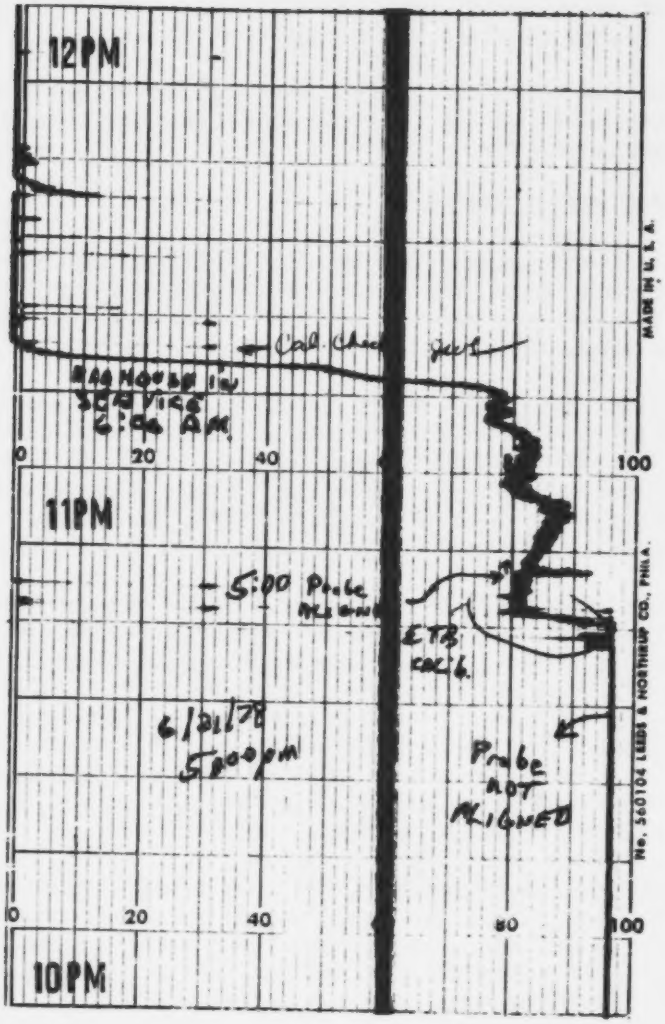
Once these steps were completed the baghouse would be in service with ash laden flue gas passing through the fabric filter system.

Actual Start-up

At this point it should be noted that, as with all start-ups, not everything proceeded as planned. The following events actually took place during start-up.

We initially brought in service compartments 1 and 3 and closed the first bypass damper on West. Compartments 16 and 18 (East) were brought in service and the first bypass damper on the East was closed. At this point the Wheelabrator-Frye service engineer felt that the ΔP across the bags was too high (approximately 0.9" WG). He felt that a ΔP around 0.7" to 0.8" WG would be better; therefore, we brought in service another compartment on each side. During this time the initial compartments put in service were developing fly ash cake and the ΔP was still slowly increasing. Because of the sufficiently high inlet and outlet temperatures through the baghouse and the bag ΔP it was decided to bring into service an additional four compartments on each side before closing another bypass damper. After a total of seven compartments were in service on each baghouse the second bypass damper was closed. The remaining compartments on both East and West baghouses were brought into service with only two bypass dampers on each baghouse in closed position. Thus, all 28 compartments were in service. At this point we were ready to close the remaining two bypass dampers on each baghouse. These bypass dampers were slowly closed and the effects on opacity can be seen in Figure 3 which shows a marked decrease in opacity only after the last bypass damper on each side was closed. At this point the baghouse was completely in service with the fabric being conditioned. The elapsed time, between first compartment being brought into service and the last bypass damper being closed, was three hours and 50 minutes.

Boiler load was maintained at 200 MW with primary fuel stabilized as coal and only igniter natural gas in service. The baghouse ΔP was approximately 1.2" WG. We expected the bag coating to require approximately 20 hours before reaching a pressure drop of 4" WG.



STRIP CHART OF UNIT II STACK OPACITY

FIGURE 3

When the pressure drop across the baghouse approached 4" WG, which took approximately 32 hours at 200 MW, the timing circuit control power was turned on and the cleaning mode selector was placed in Mode 3, which allowed the system to clean one compartment at a time.

The deflation fan was started for the Mode 3 operation. When the pressure drop reached 4" WG the cleaning cycle was initiated along with the fly ash conveying system.

IV. POST START-UP OPERATION

Approximately three weeks after the fabric filter system was initially started we were able to operate the Harrington Station Unit #2 at full load (362 MW) with only coal in service. The unit has operated at loads consistently above 200 MW and during peak periods has had 340 MW.

Adjustments are being made to the cleaning sequence, deflation, pressure and shaker operation to optimize ΔP. We plan to closely monitor and record the effects these changes have on ΔP while keeping in mind the effects on bag life. In the coming months Southwestern Public Service will continue to evaluate very carefully the cost of operating expenses due to fabric replacement and ΔP power requirements.

The cleaning sequence has been changed. These changes consisted of minor adjustments in timer relays to improve cleaning cycle efficiency. Primarily we shortened interval times and settle times. In one case we did away with the second settle timer by setting it at zero. Time for shaking can be varied from 5 to 30 seconds. At this time the shaking period is 23 seconds. These adjustments have improved cleaning efficiency, but with only 30 days of operating experience there is much work left to be done in this area. See Figures 4A and 4B for original and current timing sequence setting.

Initially the deflation ΔP across the fabric was specified to be 0.5" WG. As load was varied with a manually controlled damper on the deflation fans, the ΔP was not consistent; therefore, some "pancaking" of the bags occurred. An automatic control device for the deflation fan dampers will be installed soon to resolve this difficulty.

V. SPECIAL TESTING

Southwestern Public Service Company has contracted with EPA to performance test the Harrington Station, Unit #2, fabric filter system. The objectives of the tests are to characterize the flue gas, fly ash and fabric under operating conditions for one year. Besides the manual monitoring and testing of flue gas and fabric filter operation and maintenance, continuous data processing will be performed on over 60 primary pieces of data. This continuous monitoring and data processing will be in service within the next few months. Information will also be collected on fuel quality and operating parameters of the

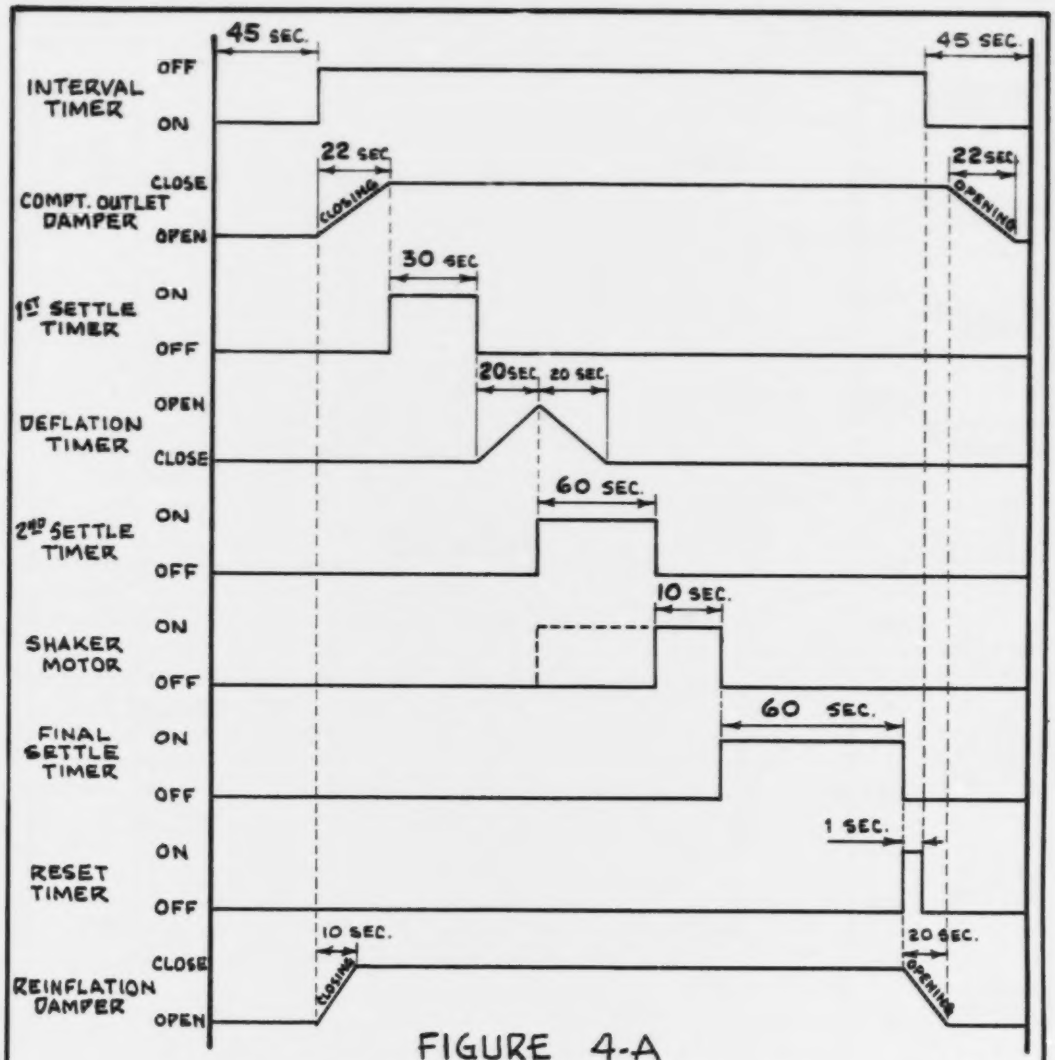

45 SEC.
45 SEC.
INTERVAL TIMER
OFF
ON
22 SEC.
22 SEC.
COMPT. OUTLET DAMPER
CLOSE
OPEN
CLOSING
OPENING
30 SEC
1ST SETTLE TIMER
ON
OFF
20 SEC.
20 SEC.
DEFLATION TIMER
OPEN
CLOSE
60 SEC.
2ND SETTLE TIMER
ON
OFF
10 SEC.
SHAKER MOTOR
ON
OFF
60 SEC.
FINAL SETTLE TIMER
ON
OFF
1 SEC.
RESET TIMER
ON
OFF
10 SEC.
20 SEC.
REINFLATION DAMPER
CLOSE
OPEN
CLOSING
OPENING

FIGURE 4-A

TYPICAL TIMING SEQUENCE OF FABRIC CLEANING

SETTINGS AT INITIAL START-UP

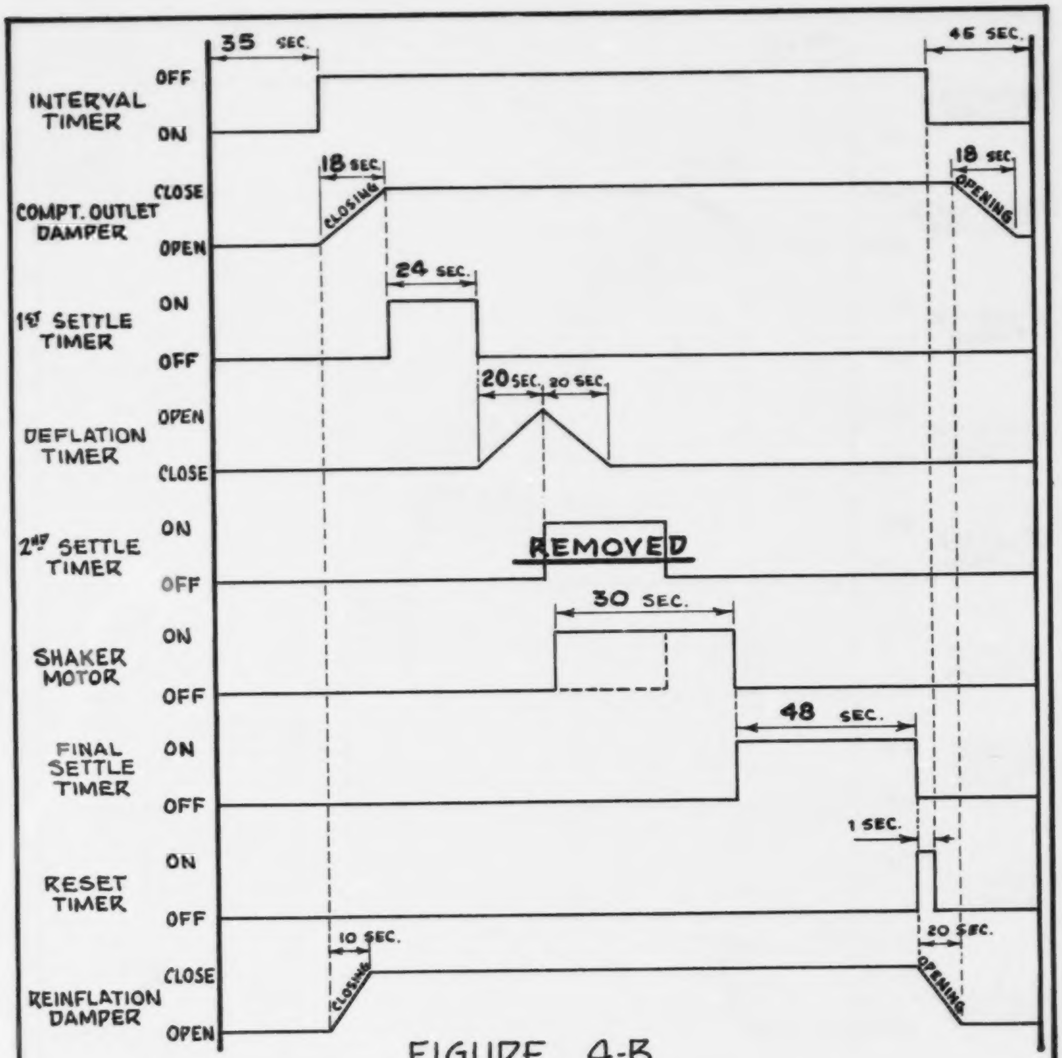

35 SEC.
45 SEC.
INTERVAL TIMER
OFF
ON
18 SEC.
18 SEC.
CLOSING
OPENING
COMPT. OUTLET DAMPER
CLOSE
OPEN
24 SEC.
1ST SETTLE TIMER
ON
OFF
20 SEC.
20 SEC.
DEFLATION TIMER
OPEN
CLOSE
2ND SETTLE TIMER
ON
OFF
REMOVED
30 SEC.
SHAKER MOTOR
ON
OFF
48 SEC.
FINAL SETTLE TIMER
ON
OFF
1 SEC.
RESET TIMER
ON
OFF
10 SEC.
20 SEC.
CLOSING
OPENING
REINFLATION DAMPER
CLOSE
OPEN

FIGURE 4-B

TYPICAL TIMING SEQUENCE OF FABRIC CLEANING

CURRENT SETTINGS AS OF JULY 10, 1978

350 MW unit. Information from this study will be provided at a later date.

VI. SUMMARY

After 30 days of operation the fabric filter system selected by Southwestern Public Service for emission control on Harrington Station, Unit #2 is doing well. The overall start-up plan implemented by the Company worked effectively and, furthermore, upon initial start-up the control system functioned properly, the system cleaned the flue gas and there were no dew point problems.

It is remarkably impressive to view the two stacks at Harrington Station and compare the opacity of Unit #2 with Unit #1. Southwestern Public Service is continuing to study and evaluate the fabric filter system and optimize operating parameters for efficient flue gas cleaning. In the months to come a more complete and comprehensive evaluation of the system's start-up and operation can be made.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Mrs. Sherry Kunka, Technical Writer, Southwestern Public Service Company, in the preparation and editing of this paper.

APPLYING HIGH VELOCITY FABRIC FILTERS TO COAL FIRED INDUSTRIAL BOILERS

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Presented at the Symposium on the Transfer and Utilization of Particulate Control Technology, Sponsored by the Particulate Technology Branch - Industrial Environmental Reserach Laboratory, U.S. Environmental Protection Agency at the University of Denver, Denver, Colorado, July 24-28, 1978.

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ABSTRACT

In the summer of 1973 a pilot scale investigation was initiated with the purpose of determining the techno-economic feasibility of applying a fabric filter dust collector to industrial coal fired stoker boilers. The pilot facility was installed on a slip stream of one of the two 60,000 lbs./hr. boilers at Kerr Industries in Concord, North Carolina. Filter media evaluated were Nomex® felt, Teflon® felt, Gore-Tex® , and Dralon® -T.

In 1976, a full scale fabric filter dust collection system was designed, fabricated and installed on each of the two Kerr boilers. In December of 1976, both dust collectors were brought on stream under an EPA Demonstration Program, with the acquisition of bag life data and the evaluation of the relationship between overall performance and on-stream time as major goals. Initially, one filtration system employed Teflon felt as the filter media while the second system employed Gore-Tex, a PTFE laminate on PTFE woven backing. Performance and economic evaluations were determined for both houses.

INTRODUCTION

In 1973 Enviro-Systems & Research, Inc. was awarded an EPA contract, the purpose of which was to determine the technical and economic feasibility of employing fabric filter dust collectors for fly ash emission control, particularly as applied to industrial boilers. Initially the program was jointly funded by the EPA, Kerr Finishing Division of Fabrics-America and ES&R, Inc.(1) The Kerr plant, located in Concord, North Carolina, served as the host site for the program and ES&R manufactured and installed the pilot facility. The pilot plant program provided short term performance data, including dust removal efficiencies and pressure drops for a number of filter media.(2) This data and preliminary economic analysis indicated that long term bag life and performance studies were warranted. EPA thus decided to award a contract for the full scale demonstration of this approach to fly ash control. The initial demonstration contract awarded to FabricsAmerica with ES&R as the major subcontractor called for ES&R to design, fabricate, install and then operate the two fabric filter units for a period of one year.

The purpose of the demonstration program is the testing of a full-scale fabric filter system installed on an industrial coal-fired stoker boiler. Data generated by the demonstration includes general operating parameters, as well as media changes, media life data, and particle size removal efficiencies as a function of on-stream time. This long term data is necessary for accurate economic analyses to be performed.

The demonstration program's baghouses were designed to filter the fly ash emissions from the two 60,000 lb./hr. coal-fired stoker boilers at Kerr Industries. Each house can handle 35,000 ACFM of air at 400° F. The average inlet dust concentrations range between 0.4 and 0.5 grains/

DSCF. Before the pilot study was begun in 1973, the North Carolina Air Quality Division performed particulate emissions tests on Kerr's No. 2 boiler. Emissions were found to be 131.4 lb./hr. and 135.6 lb./hr. when allowable emissions for conditions during this test were only 25.1 lb./hr. and 27.8 lb./hr.

BAGHOUSE OPERATION

The baghouse is brought on line by closing the boiler stack damper and opening the system inlet damper. Figure 1 is a baghouse system schematic. The dust ladened gas then enters one end of the unit, passes through the tapered duct, into the classifier, and then through the bags. The classifier (Figure 2) forces the dirty gases to change direction 90°, then 180°. This quick directional change forces the larger and heavier particles out of the flow so that they fall directly into the hopper. The gas flows through the fabric filter into the center of the bags, leaving the particulate on the outer surface of the bags where it is removed periodically during the cleaning cycle. The clean gas then flows up through the center and out the open top of the filtering bag into a center exit plenum via an open damper in the cell above the tube sheet.

The bags are cleaned one cell (36 bags) at a time by a Shock-Drag Cleaning System designed to prolong life by minimizing distortion of the fibers. During the cleaning cycle, clean gas enters the cell through the pneumatic damper and is forced down the filter bag, opposite to the normal flow direction. The bag expands with a shock so that the cake is cracked and the particulate falls off the bag into the hopper. After the shock has expanded the filter bag and broken off the cake, the clean air continues to flow providing a drag which pushes and pulls the dust particles away from the fabric. More details are available in the first year demonstration report.(3)

HARDWARE DESCRIPTION

The baghouses were installed and brought on-stream in 1976. The two houses are identical in terms of the basic hardware. Each house contains eighteen (18) cells with thirty-six (36) 5" diameter X 8' 8" long bags in each cell, thus each house contains a total of 7,440 square feet of cloth. The bags are placed over rigid wire "cages" and set into a tube sheet at the top of each cell via snap rings (Figure 3). Initially, House No. 1 contained 648 Teflon felt bags and House No. 2 contained 648 Gore-Tex bags. During the first year of operation one cell (36 bags) of Gore-Tex was replaced by the Huyck experimental felted glass media and subsequently a second cell of Gore-Tex bags was replaced by a 22.5 oz. woven glass media. In early 1978, one cell of 15.0 oz. woven glass bags and three Nomex felt bags were introduced into Baghouse No. 2 for on-stream evaluation. Below each house are three pyramid hoppers for fly ash collection and subsequent discharge into barrels. The hoppers were chosen over screw conveying to eliminate the problems associated with screw conveying

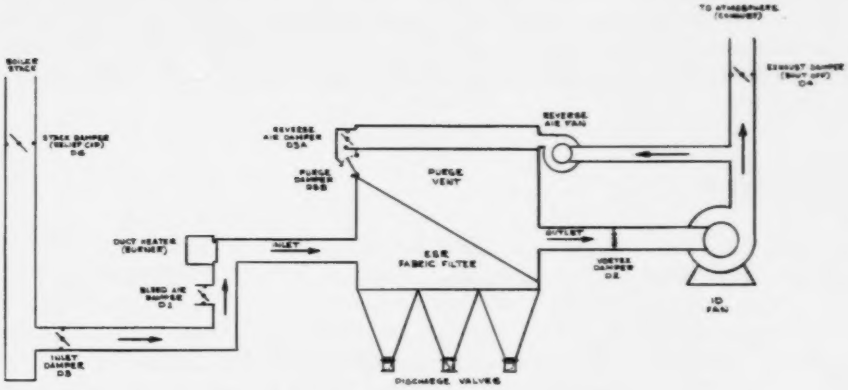

TO ATMOSPHERE (CHIMNEY)
BOILER STACK
EXHAUST DAMPER (SHUT OFF) D4
STACK DAMPER (RELIEF CAP) D6
REVERSE AIR DAMPER D5A
REVERSE AIR FAN
PURGE DAMPER D5B
PURGE VENT
DUCT HEATER (BURNER)
INLET
OUTLET
ESR FABRIC FILTER
VORTEX DAMPER D2
BLEED AIR DAMPER D1
ID FAN
INLET DAMPER D3
DISCHARGE VALVES

Figure 1. BAGHOUSE SYSTEM SCHEMATIC

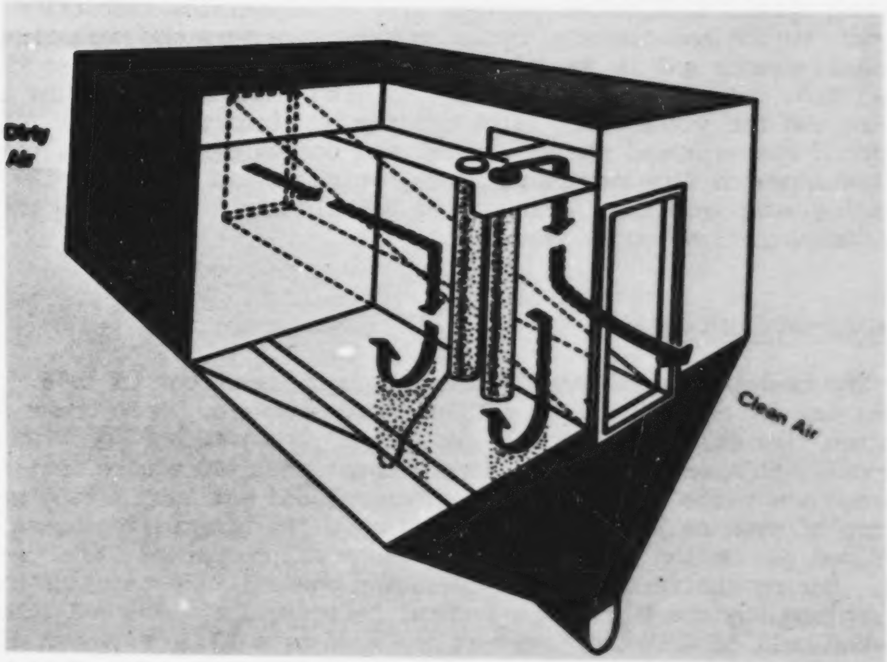

Dirty Air
Clean Air

Figure 2. THE CLASSIFIER: THE FIRST STEP IN GAS CLEANING

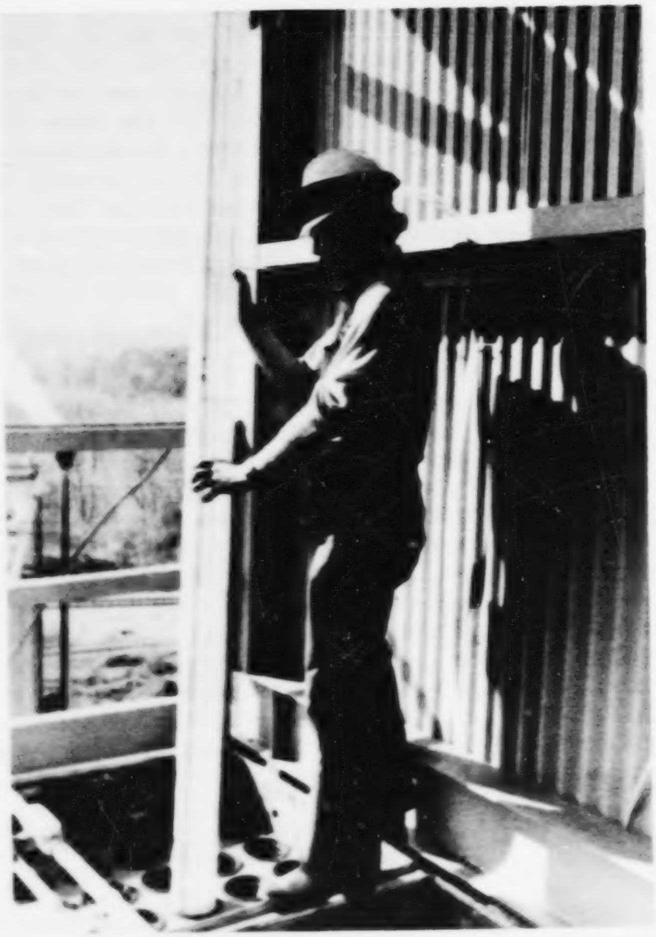


Figure 3. VIEW OF A BAG ON ITS RIGID CAGE BEING PUSHED IN THE TUBE SHEET

fly ash. The houses share a common "penthouse" which aids testing in inclement weather.

The system is arranged so that the entire operation of both baghouses is controlled from a console located in the control house. The control panel (Figure 4) is arranged in three parts, with test instrumentation located in the center and the baghouse controls at the left and right. When set up for automatic operation, either baghouse can be started and stopped from controls located in the boiler house; however, provision was included on the control house console for locking-out the boiler house start function. An auxiliary heater can be employed to preheat the house prior to baghouse start-up and it can also be employed to purge the house at shutdown. The vortex damper is employed to maintain a predetermined pressure at the boiler stack in an attempt to prevent the dust collection system pressure drop fluctuations from influencing the boiler operation. The control system includes automatic preheat, start-up and purge mode and operation of the vortex is also automated. Certain situations will cause alarms and/or an automatic shutdown of the system. Also a number of temperatures, pressures, and opacities are permanently recorded.

Several changes have been made in the system, both to solve unanswered questions as well as to create optimum operating conditions. Recently, one multi-cyclone was rebuilt so that a comparison of particle removal efficiency with and without multi-cyclones can be made. In order to obtain more forceful cleaning air flow, thus more effective cleaning, two different measures were undertaken. On Baghouse No. 1, the flapper dampers have been replaced by poppet valves. Preliminary observations indicate that the dampers now seal better and have increased the plenum pressure. A different method was applied to Baghouse No. 2. In order to more effectively clean the bags after a dew-point excursion and to allow for a higher A/C ratio, a combination pulse-jet - reverse-air flush system was installed. Early results show that the unit can clean down to a pressure drop across the house of 6" W.G. even after dew-point excursions and after pressure drop excursions to over 10" W.G.

FILTER MEDIA

The fabrics initially considered for use in the demonstration project were those used in the pilot project - Teflon felt Style 2663 (21-29 oz./yd.^{2}), a tetrafluoroethylene fluoro-carbon; Gore-Tex (4-5 oz./yd.^{2}), a microporous Polytetrafluorethylene (PTFE) membrane on a woven PTFE fabric backing; Dralon-T felt (13-15 oz./yd.^{2}), a homopolymer of 100% acrylonitrile; and Nomex felt (14 oz./yd.2), a high temperature resistant nylon fiber (polyamide). Of these media, the Teflon felt and the Gore-Tex PTFE laminate were selected as the first to be tested for bag life studies.

The Teflon felt in Baghouse No. 1 produced no failures during the first year of operation. After nineteen months, however, fifty-one (51) bags had failed yielding an average replacement rate of about 5% per year.

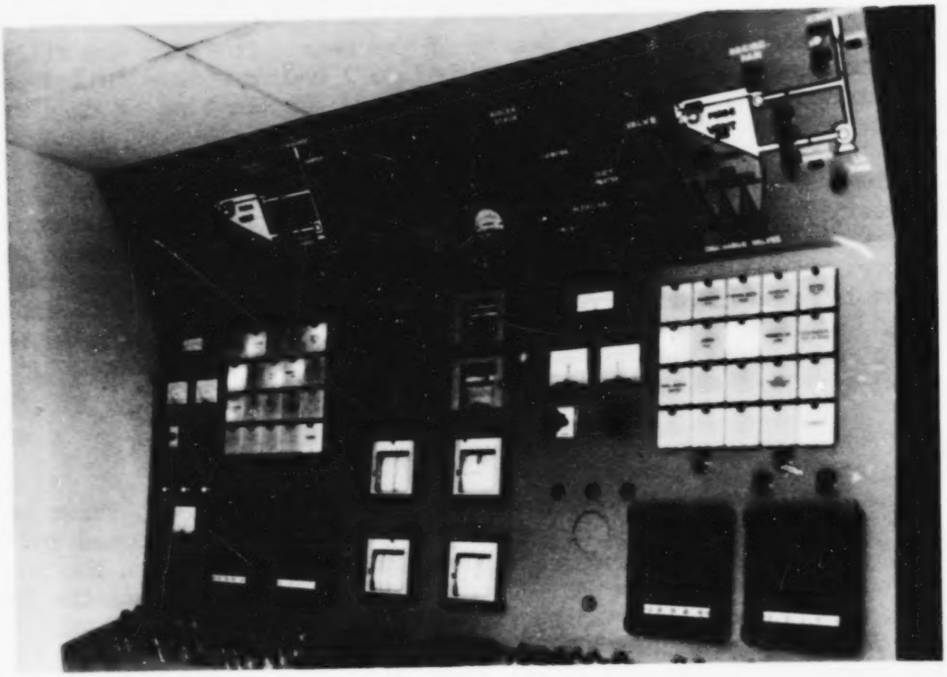


Figure 4. THE CONTROL PANEL

During this time the house was on-stream five or six days per week and the only maintenance was industrial vacuuming at intervals of approximately six months. It is believed that in some instances the failure was accelerated by the removal and replacement of the bags during the manual cleaning operations.

Baghouse No. 2 was initially outfitted with Gore-Tex bags only. Thirty-six (36) bags in one cell were replaced by Huyck experimental glass bags in March of 1977. To date there have been no failures of the Huyck bags. By the end of the first year more than 10% of the Gore-Tex bags had failed. A large number of these were probably damaged by the vacuum cleaning and the movement of the bags. One cell was filled with Globe Albany 22½ oz. bags in May of 1977 and none have failed in the fourteen months they have been on-stream. At the time of this writing 100 Gore-Tex bags have failed.

Other media have been put into Baghouse No. 2. Cell 5A was filled with thirty-six Globe Albany 15 oz. bags in February of 1978 and four had failed in the first four months. It would appear that the heavier Globe Albany fabric resists wear by abrasion and by acid attack much better than the 15 oz. fabric. Also, three Nomex bags were placed (one each) in Cells 1A, 4A, and 9A in February of 1978 with all three failing in less than two weeks. Table 1 lists the bag replacements to date.

DATA

Some of the most meaningful results acquired during the first year and a half of operation center around the opacity data collected and the pressure drops across the house. Transmissometers located on the inlet to and outlet from Baghouse No. 2 record the gas opacity while the house is operating. The inlet opacity range has run from 18% to 80% with the normal being approximately 40%. The outlet range is 4% to 20% with normal operation showing about 7%. Outlet opacity ranging above 10% is a good indication of a broken bag or bags. Overall, the baghouse seems to serve as an opacity "dampering" device in that large inlet increases (i.e., during grate cleaning) produce no noticeable changes in outlet opacity, regardless of the pressure drop increase experienced during grate cleaning.

Across-house pressure drops have been generally higher than those experienced in the pilot unit. The full-scale houses are normally set to run at air-to-cloth ratios of between 4/1 and 5/1. At these air-to-cloth ratios, the pilot plant operated with a Δp of about 3" W.G. for Teflon felt and a Δp of about 5" W.G. for Gore-Tex. Continuous monitoring devices show that normal operation of the full scale houses with Teflon felt produces a Δp of about 6" W.G. and with the Gore-Tex of about 10" W.G. Reasons for this increase include dew point excursions, longer on-stream time for the bags, and the removal of the cyclones at the beginning of the demonstration program. The highest pressure drops were associated with dew point excursions. Pearling of the dust cake

Table 1. LIST OF BAG REPLACEMENTS
Baghouse No. 2

Bag Type	No. of Bags Replaced	Date	Comments
Huyck	36	3/28/77	Put Into Cell 6A*
Gore-Tex	8	4/77	Shrinkage/Material Failure
Gore-Tex	25	5/77	Damage During Cleaning
Globe Albany (22½ oz.)	36	5/24/77	Put In To Fill Cell 3A*
Gore-Tex	30	7/77	Holes/Tears Due to Maintenance
Gore-Tex	3	10/77	Center Shredded (1 Bag); 2 Bags With 1" Diameter Holes
Gore-Tex	14	11/77	1-1½" Holes at Bag-Rib Contact (Upper 2 Ft. of Bag)
Globe Albany (15 Oz.)	36	2/21/78	Installed to Fill Cell 5A*
Nomex Felt	3	2/21/78	One Each, Cells 1A, 4A, and 9A*
Nomex Felt	3	3/78	Failed, Multiple Holes in Each
Globe Albany (15 Oz.)	2	4/7/78	Failed - Holes Near Tube Sheet
Teflon Felt	1	6/1/78	Failed - Holes & Shredding 3" From Bottom
Globe Albany (15 Oz.)	2	6/30/78	Failed - Holes
Teflon Felt	50	6/30/78	Failed - Worn

*Note: Cells are numbered from inlet to outlet side of the baghouse with the "A" side of the house to the left of the inlet duct when looking down on the baghouse.

occurred indicating the presence of moisture. With the original cleaning system it was necessary to vacuum the bags manually after a dew-point excursion had occurred. The present cleaning system incorporating a pulse-jet in combination with reverse-air has successfully cleaned down the bags even after numerous dew-points have occurred.

The particle size removal efficiencies of the pilot unit and full-scale unit differ markedly in the removal of larger particles. The "average" curves are roughly parallel but the full scale unit shows a greater percentage of larger particles. Possibly this difference was created by the elimination of the multi-cyclone before the demonstration study began. The multi-cyclone would have removed the larger particles to be reinjected into the boiler. The multi-cyclone for House No. 1 is being rebuilt in order to check this theory.

ECONOMICS

Capital and operating costs for the two baghouses at Kerr are based on actual 1978 costs. The "installed" costs were computed by adding the hardware costs to 70% of the hardware costs (an estimate of erection costs) and then adding the bag cost for each unit.

For all air-to-cloth ratios, a baghouse employing Teflon felt as the filter media is the most expensive at \$6.94, \$3.47, \$2.42 and \$2.02 per ACFM for A/C of 2.9, 5.8, 8.9 and 11.3, respectively. A baghouse system employing the 15 oz./yd.^{2} Globe Albany bags is the least expensive overall and at the same air-to-cloth ratios is \$5.75, \$2.88, \$2.02 and \$1.71 per ACFM. Figure 5 shows a comparison of the filter media for installed costs vs. air-to-cloth ratio.

As seen in Figure 6, the 15 oz./yd.^{2} Globe Albany bags also have the lowest annual operating costs at \$0.175, \$0.143, \$0.189 and \$0.266 per ACFM at air-to-cloth ratios of 2.9, 5.8, 8.9 and 11.3. Based on an annual replacement rate of 25%, the increasing costs at higher air-to-cloth ratios are due primarily to the increasing pressure drop. Except for very low air-to-cloth ratios (where Teflon felt again has the highest costs), the Gore-Tex bags have the highest operating costs. This is due to the higher pressure drop across a Gore-Tex house overshadowing the bag costs. Still, the operating costs are only \$0.455, \$0.309, \$0.344 and \$0.374 per ACFM at air-to-cloth ratios of 2.9, 5.8, 8.9 and 11.3. However, increasing the pressure drop required, as in Figure 7, does increase the operating costs.

Annualized capital costs have been calculated based on a 15 year hardware depreciation of 6 2/3% of the installed cost per year. Insurance and miscellaneous costs assumed equal to the amount of depreciation produce annualized costs consisting of this 13.3% of the installed costs plus the annual operating costs. The results produced by this examination (Figure 8) reflect the trend seen in the operating costs. Globe Albany Albany 15 oz./yd.^{2} baghouses were the lease expensive in terms of

Figure 5. COMPARISON OF FILTER MEDIA FOR INSTALLED COST VS. AIR-TO-CLOTH RATIO

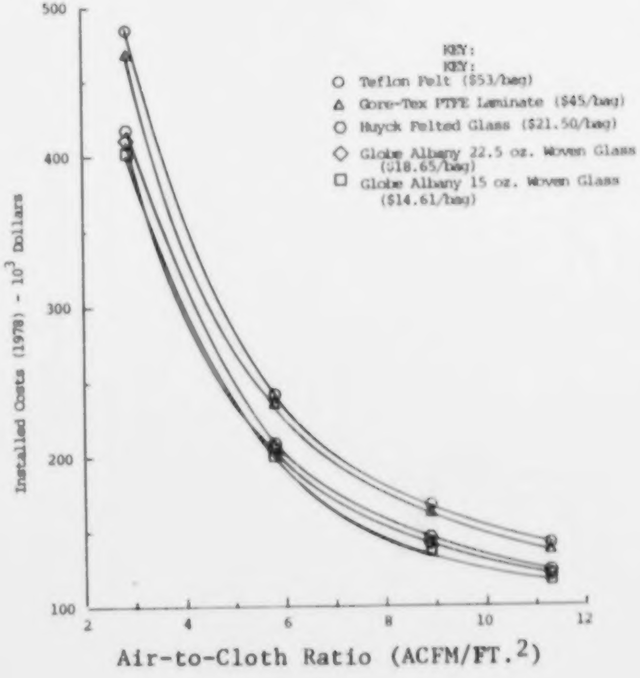


Figure 6. COMPARISON OF FILTER MEDIA FOR ANNUAL OPERATING COST VS. AIR-TO-CLOTH RATIO

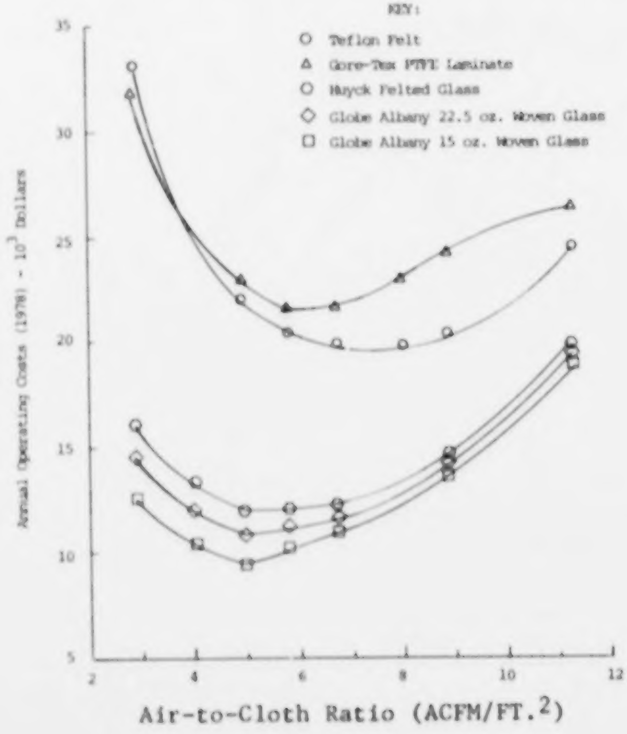


Figure 7. THE EFFECT OF INCREASING PRESSURE DROP ON ANNUAL OPERATING COSTS, CASE OF TEFLON FELT

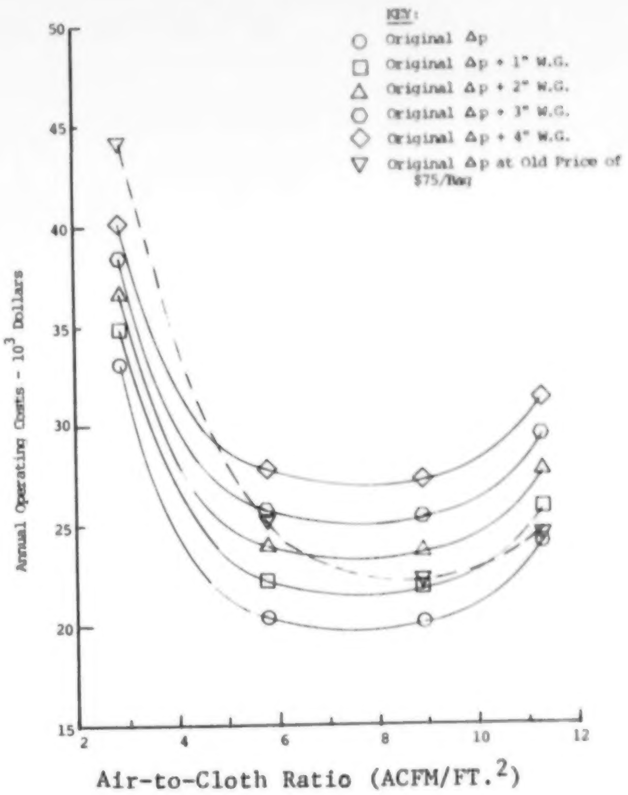
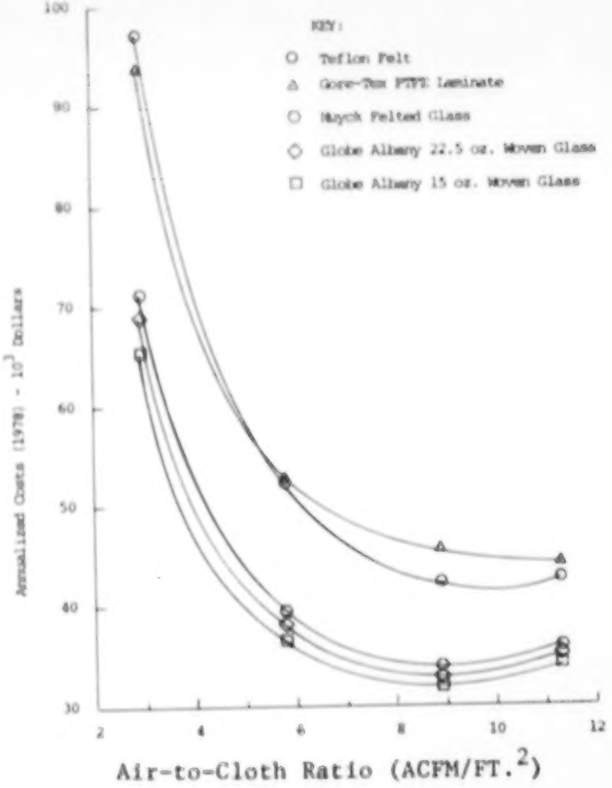


Figure 8. COMPARISON OF FILTER MEDIA FOR ANNUALIZED COSTS OF CONTROL VS. AIR-TO-CLOTH RATIOS



annualized costs at $0.94, $0.53, $0.46 and $0.49 per ACFM at the air-to-cloth ratios mentioned previously. With the exception of air-to-cloth ratios less than about 3.5, the houses supplied with Gore-Tex bags were the most expensive at $1.34, $0.75, $0.65 and $0.63 per ACFM.

FUTURE PLANS

The EPA has elected to exercise the three proposed options, thus the baghouses will be operated and tested through 1979. The Teflon felt filter media will remain in House No. 1 to extend both bag life data and media performance data as a function of on-stream time.

The Gore-Tex bags in House No. 2 will be replaced by 22 oz. woven glass bags in early August. While in the house data acquired for the media will include filter media property changes as a function of on-stream time, bag life and general operating data, and particle size removal efficiencies, as well as general economics.

Later on in the program one baghouse will be operated as an SO_2 removal system. This portion of the study will include data on SO_2 removal performance, effects of the injected sorbants on the filter media, and capital and operating costs.

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(2)McKenna, J. D., Mycock, J. C., and Lipscomb, W. O., "Applying Fabric Filtration to Coal Fired Industrial Boilers - A Pilot Scale Investigation", August - 1975, NTIS PB-245 186.

(3)McKenna, J. D., and Brandt, K. D., "Demonstration of a High Velocity Fabric Filtration System Used to Control Fly Ash Emissions", Presented at the Third Symposium of Fabric Filters for Particle Collection in Tucson, Arizona on December 5-6, 1977.

(4)McKenna, J. D., Mycock, J. C., Brandt, K. D. and Szalay, J. F., "Assessment of a High Velocity Fabric Filtration System Used to Control Fly Ash Emissions". (To be published by the U.S. Environmental Protection Agency.)

ACKNOWLEDGEMENTS

This program was sponsored by the Federal Environmental Protection Agency with participation by Kerr Industries and Enviro-Systems & Research, Inc.

FABRIC FILTER RESEARCH & DEVELOPMENT FOR PC BOILERS USING WESTERN COAL

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ABSTRACT

In the late 1950's the City of Colorado Springs, Department of Public Utilities, became concerned about the dwindling supply of natural gas; hence, new electric power plant boilers were designed to burn western low-sulfur coal. The city of Colorado Springs is located in a valley with the Rocky Mountains in the background. This location, plus the clear skies associated with the high altitude, causes visible emission to be accentuated. Thus, to satisfy local interests, particulate control equipment must not only meet air pollution regulating requirements but must also result in near-zero visible emissions. Encouraging results using baghouse filters with pulverized coal boilers fired with eastern coal and stoker-fired western coal boilers have led to a contract with Envirotech for an evaluation of a baghouse filter using the pulverized coal-fired western coal boilers of Martin Drake Unit #6.

The main baghouse, now being erected, is a conservative design using reverse air cleaning. Research and development tests will be performed on a parallel flow, slipstream test filter incorporating 16 full-size bags. Tests will be performed to evaluate and optimize the filter operation relative to inlet particulate loading, air-to-cloth ratio, reverse air cleaning parameters, and the use of improved fabrics. Extensive testing is planned to evaluate the injection of sodium compounds for suppression of sulfur oxides and nitrogen oxides.

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INTRODUCTION

In March 1977, the City of Colorado Springs entered into a cooperative contractural agreement with Buell Emission Control Division, Envirotech Corporation, to perform a Research and Development Product Optimization Program to evaluate a fabric filter baghouse for Martin Drake Unit #6. This unit is an 85-megawatt pulverized-coal-fired utility boiler with a flue-gas volume of 400,000 ACFM at full load.

The baghouse concept was selected by Colorado Springs as the best emission control device to meet current and anticipated regulations and to satisfy a local need to minimize stack emission visibility. Stack gas visibilities in Colorado Springs are accentuated because of three factors:

1. Generating plants are located in the metropolitan area.
2. The sky is normally very clear due to the high altitude.
3. Backdrop of the city is the western slope of the Rocky Mountains.

The baghouse selection was based on the encouraging experience of others using pulverized eastern coal and on a stoker-fired western coal installation. This will be the first installation of a baghouse filter for controlling emission from a utility burning pulverized, low-sulfur western U.S. coal.

Two program features are to be accomplished simultaneously. First, the program will upgrade the stack emission control of the existing, middle-aged utility boiler by retrofitting it with a Buell baghouse filter. Second, the program includes research efforts to both define the optimum operating parameters of the baghouse and to serve as a technical basis for advancing the design of future installations.

The main baghouse is a conservative design. Parallel to the main baghouse is a "slipstream" experimental unit, shown in Figure 1, that will be used to both optimize the operation of the main baghouse and to develop the technical basis for future installations. The pilot unit will allow testing under extreme operating conditions without compromising the capability of the main baghouse to function as an air pollution control device.

GOAL AND OBJECTIVES

The overall goal of the program is to advance the "state of the art" of fabric filtration for particulate and gaseous pollution control. The four interrelated objectives to approach this goal, shown in Figure 2, are to evaluate the theoretical collection mechanisms of fabric filtration, perform optimization tests on the fabric filter system, investigate the effectiveness of sulfur dioxide suppression in a fabric filter baghouse by injecting sodium-based compounds such as nahcolite, and finally to develop a performance model to simulate the fabric filtration process.

INVESTIGATION AND EVALUATION OF COLLECTION MECHANISMS

The existing theory of the fabric filter collection mechanisms of impaction, interception and diffusion will be analyzed. These mechanisms are illustrated in Figure 3. The data obtained from the testing will constitute a foundation for developing a performance model. This model will then be used to optimize the fabric filter system.

OPTIMIZATION TESTS

Testing of the various operation and design parameters are to be conducted on both the full-scale unit and the pilot unit. The testing of the full-size unit is limited to those conditions which will not cause irreversible damage or adversely affect the integrity of the unit.

Checkout Tests

The first testing task, Figure 4, is to check out the equipment and to establish the nominal operating parameters.

Particle Loading Tests

In the second task, Figure 5, the effect of inlet particle loading is to be evaluated. Two series of EPA Method 5 tests are to be conducted simultaneously on both the full-scale unit and the pilot unit. The first series of tests will be conducted while bypassing the existing mechanical collector. Inlet and outlet particle size distributions will be analyzed from both units. The second series of tests are to be conducted in an identical manner except with the mechanical collector in service. The results of these tests will establish the relationship of collection efficiency with respect to particle size and the role of large particles on the collection mechanism. These series of tests will establish the operating relationship between the full-scale unit and the pilot unit for correlation of data results from the remaining tasks.

Air-to-Cloth Tests

The third task is to vary the air-to-cloth ratio, Figure 6. The air-to-cloth ratio will be increased from 1:1 to over 4:1. Both the full-scale unit and the pilot unit will be varied in the lower air-to-cloth ratio ranges. This again will help establish a correlation between the two units. Only the pilot unit air-to-cloth ratio will be increased once the air-to-cloth ratio exceeds 2:1. The reverse air cleaning cycle will be adjusted as required for each change in air-to-cloth ratio. The results will be evaluated with respect to effects on overall efficiency deterioration of the fabric filter bags, and overall capital and operating costs.

Reverse Air Tests

During Test 4, Figure 7, the reverse air cleaning cycle is to be evaluated. Proper cleaning will enhance both the performance of the collector system and bag life. If the fabric is not sufficiently cleaned, system pressure drop increases resulting in higher operating costs and reduced bag life. If the fabric filter is overcleaned, increased penetration of fine particles may result, thus reducing efficiency. Overcleaning can also reduce bag life due to increased flexing. During the research and development testing period, reverse air flow rates will be decreased to as low as will effectively clean the filter.

To determine if the fabric filter bags are being overcleaned, the change in opacity when a cleaned compartment is brought back on line will be observed. In order to prevent overcleaning during the longer cycle times, the reverse air duration will be reduced to less than the maximum available time. This reduction also allows more time for dust settling after dislodgement.

The pilot unit is also provided with a shaker mechanism to test the effectiveness of shake cleaning and the combination of reverse air and shake.

Improved Fabric Tests

Test 5, Figure 8, is to evaluate improved fabrics. The effects of various types of bag construction on differential pressure, efficiency, and bag life will be evaluated. The different types of bag construction that will be evaluated are fabric fiber shapes, needled fabrics, fabric materials, and fabric finishes. Electrostatic techniques will also be evaluated with respect to increased efficiency.

SULFUR DIOXIDE REMOVAL TEST

Presently the Colorado Springs generating units burn low-sulfur coal from northwest Colorado; hence, the sulfur dioxide emissions are well within state and federal requirements for existing sources. However, recent developments in federal regulations indicate that sulfur dioxide removal may be required regardless of fuel sulfur content. The present wet scrubber technology is difficult to apply to the semi-arid region in Colorado Springs, because of water utilization and solid-waste disposal. Therefore, it is very beneficial to utilities such as the City of Colorado Springs to find an alternate method of sulfur dioxide suppression that will minimize these environmental problems. The final task, Figure 9, to be performed in the research and development program is removal of sulfur dioxide in the flue-gas stream by dry-scrubbing techniques using sodium compounds such as nahcolite or sodium ores from dry lakes. Figure 10 is a schematic of the dry-scrubbing process. This technique has great promise for reducing capital costs and system complexity.

Nahcolite is a naturally occurring form of sodium bicarbonate which is found in the oil shale region in northwest Colorado. At present, the availability of nahcolite ore is limited since no commercial nahcolite mines exist. A limited amount of nahcolite is available from seam outcroppings and from a Bureau of Mines pilot shaft. Alternatives to nahcolite are available, such as crude dry lake ore, solar refined ore, and commercial sodium bicarbonate. These will be evaluated and considered for testing.

The first experimental phase of this task is to determine the most practical method of comminution of the sodium compounds. An evaluation of equipment and operating costs is to be made on mechanical and thermal comminution. The most cost effective means of sodium compound preparation relative to size and activity will be of importance for future applications of dry SO_2 scrubbing.

The actual injection testing is planned for two phases. The first phase will be conducted on the pilot baghouse. Various precoating and injection techniques and flow rates will be investigated. Instrumentation will be used to determine the sulfur dioxide reduction and the amount of un-reacted sodium bicarbonate.

The second phase of the sulfur dioxide removal experiments are planned to be conducted on the full-size baghouse servicing the Martin Drake Unit #6, an 85 megawatt unit. The full details of this phase will depend on the results of the pilot unit testing. Experiments are to be conducted to evaluate the disposal of the sodium sulfate-fly ash waste. Investigations will include disposal in isolated landfill, insolubilization techniques, and attempts to find beneficial uses for the waste product.

STATUS

Figure 11 shows the Colorado Springs baghouse under construction as it appeared in early-June 1978. The connection of the baghouse to the boiler is scheduled to begin August 15, 1978. Installation of the 16-bag R&D Test Device will follow hook up of the main baghouse.

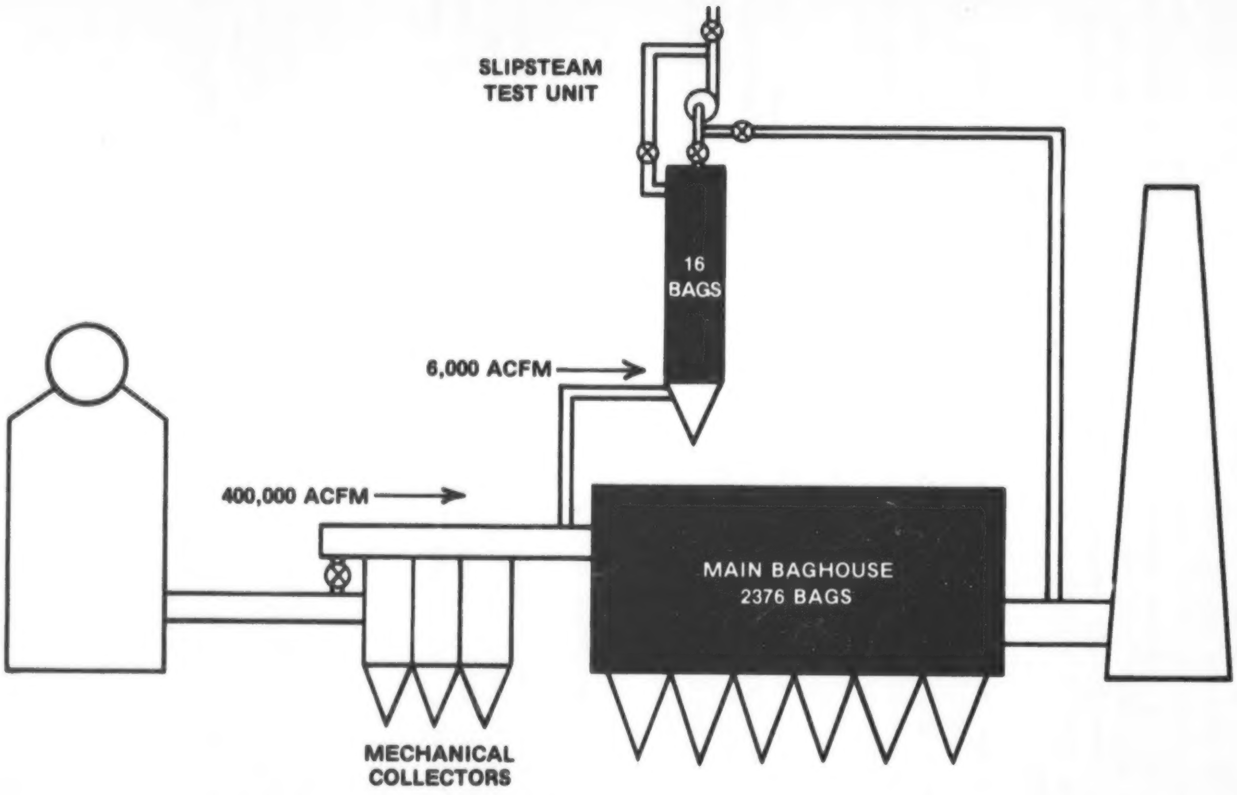

SLIPSTEAM
TEST UNIT
16
BAGS
6,000 ACFM
400,000 ACFM
MAIN BAGHOUSE
2376 BAGS
MECHANICAL
COLLECTORS

FIG. 1 MARTIN DRAKE NO. 6 FABRIC FILTER INSTALLATION

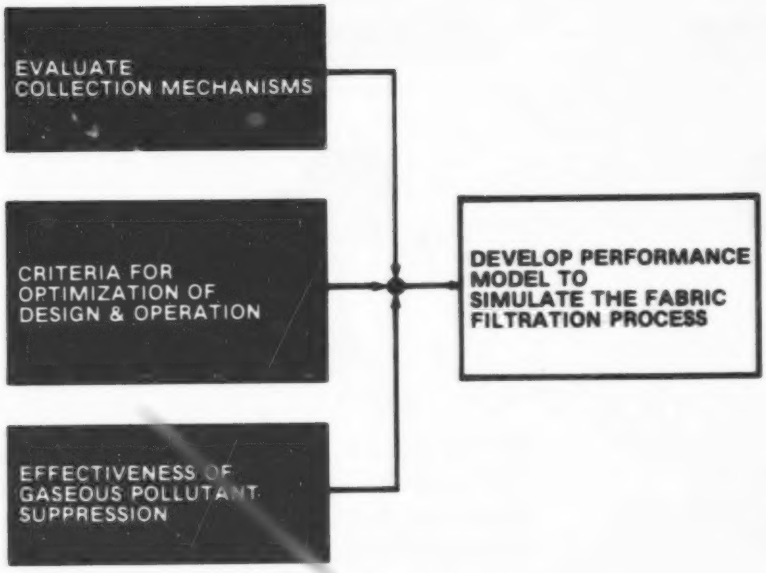
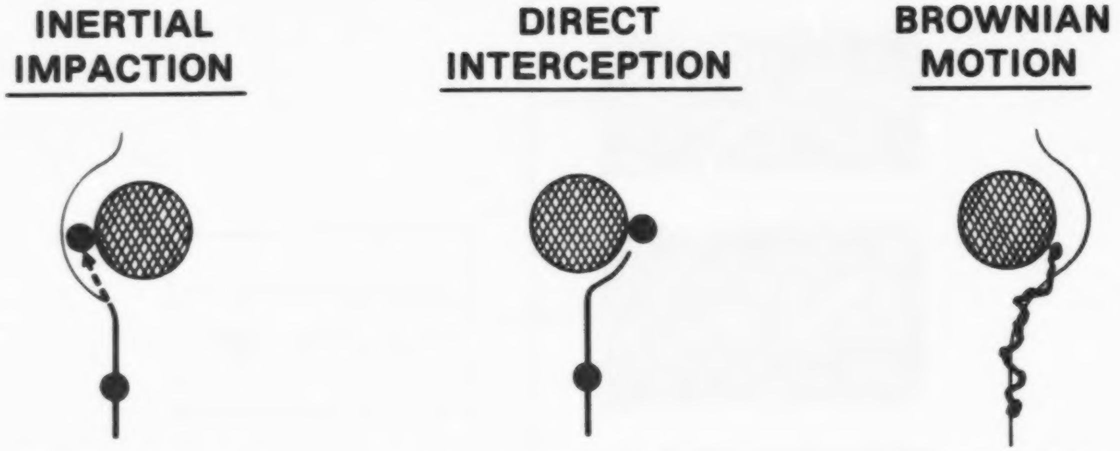

EVALUATE COLLECTION MECHANISMS
CRITERIA FOR OPTIMIZATION OF DESIGN & OPERATION
EFFECTIVENESS OF GASEOUS POLLUTANT SUPPRESSION
DEVELOP PERFORMANCE MODEL TO SIMULATE THE FABRIC FILTRATION PROCESS

FIG. 2 OBJECTIVES OF TESTING PROGRAM



INERTIAL IMPACTION

DIRECT INTERCEPTION

BROWNIAN MOTION

EFFICIENCY RELATED TO THE RATIO OF PARTICLE INERTIA TO VISCOUS DRAG

EFFICIENCY RELATED TO THE RATIO OF PARTICLE DIAMETER TO COLLECTOR DIAMETER

COLLECTION PROBABILITY ENHANCED BY MOLECULAR COLLISIONS

FIG.3 COLLECTION MECHANISMS

TASK 1

- VERIFY FUNCTIONAL OPERATION
  EQUIPMENT
  INSTRUMENTATION
- ESTABLISH NOMINAL OPERATING PARAMETERS

FIG. 4 CHECK OUT TEST

TASK 2

- BYPASS MECHANICAL COLLECTOR
- OBSERVE EFFECTS OF INCREASED LOADING
    - PRESSURE DROP
    - EFFICIENCY
    - CLEANING CYCLE

FIG. 5 INLET LOADING

TASK 3

- INCREASE AIR FLOW (A/C $<$ 4)
- DECREASE NUMBER OF BAGS (A/C $>$ 4)
- MAX. Δp = 8 inches
- OBSERVE EFFECTS OF INCREASING A/C
    - LIFE
    - EFFICIENCY
    - CLEANING CYCLE

FIG. 6 AIR TO CLOTH RATIO

TASK 4

- REVERSE AIR FLOW RATE
- CYCLE TIME
- REVERSE AIR DURATION
- REVERSE AIR & SHAKE

FIG. 7 REVERSE AIR CLEANING

TASK 5

- IMPROVE ΔP/EFFICIENCY CHARACTERISTICS
- LONGER LIFE
- TECHNIQUES
  - ELECTROSTATIC AUGMENTATION
  - FIBER SHAPES
  - NEEDLED FABRICS
  - FABRIC MATERIALS
  - SURFACE FINISHES

FIG. 8 IMPROVED FABRICS

TASK 6

- SODIUM MATERIAL SUPPLY SURVEY
- COMMINUTION EXPERIMENTS
  - MECHANICAL
  - THERMAL
- INJECTION TESTS
  - CONTINUOUS
  - PRECOATING

FIG. 9 SODIUM COMPOUND INJECTION

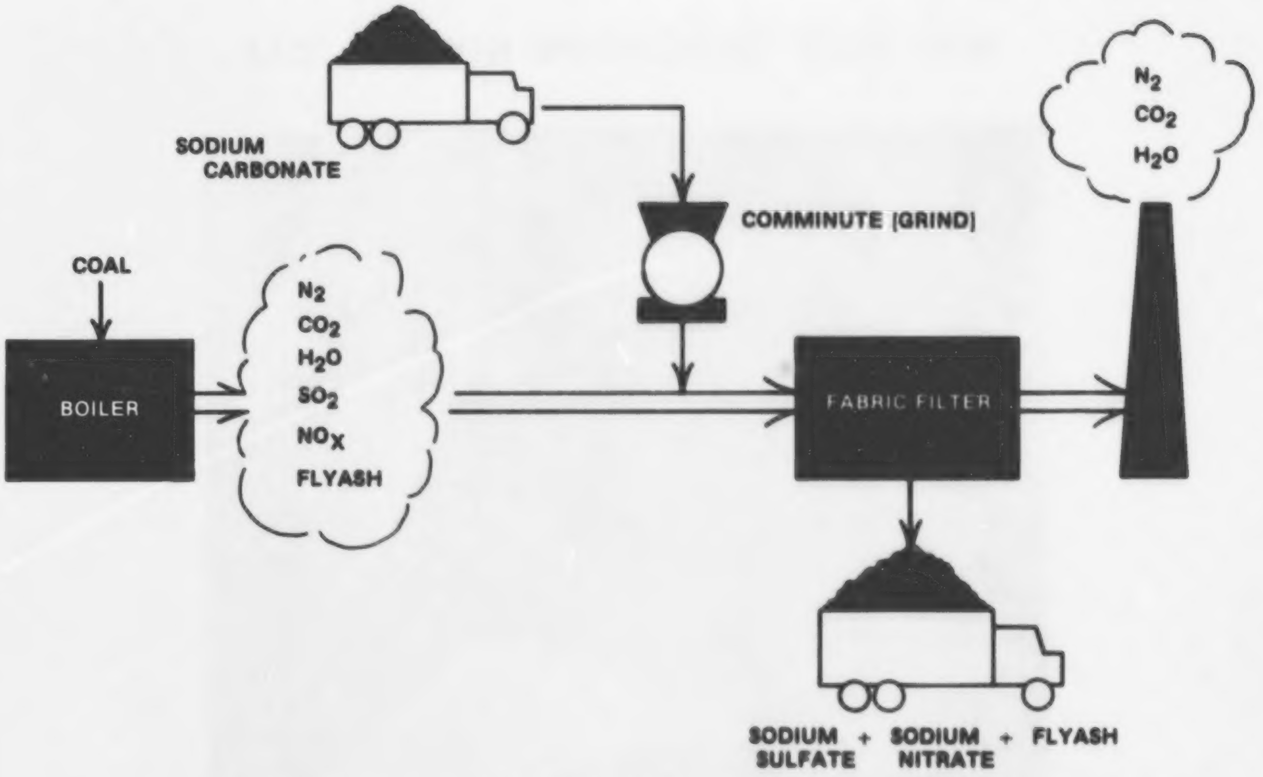

SODIUM CARBONATE
COMMINUTE [GRIND]
COAL
BOILER
N_2
CO_2
H_2O
SO_2
NO_X
FLYASH
FABRIC FILTER
N_2
CO_2
H_2O
SODIUM SULFATE + SODIUM NITRATE + FLYASH

FIG. 10 "DRY SCRUBBING" WITH SODIUM SALTS

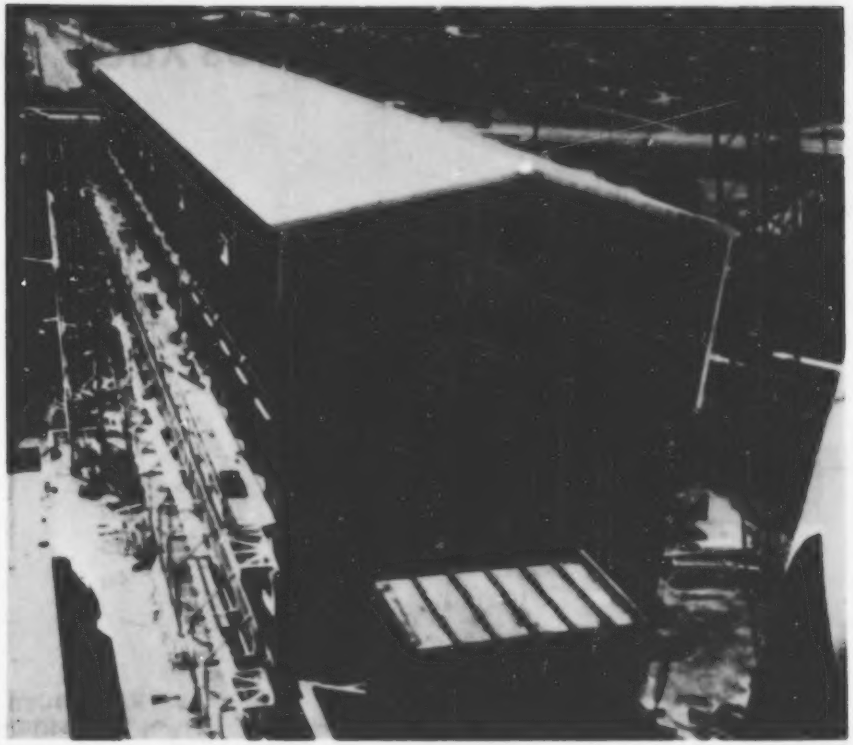


FIG. 11 MAIN BAGHOUSE, JUNE 1978

A PILOT PLANT STUDY OF VARIOUS FILTER MEDIA APPLIED TO A PULVERIZED COAL-FIRED BOILER

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Presented at the Symposium on the Transfer and Utilization of Particulate Control Technology, Sponsored by the Particulate Technology Branch - Industrial Environmental Research Laboratory, U. S. Environmental Protection Agency at the University of Denver, Denver, Colorado, July 24-28, 1978.

ABSTRACT

A pilot scale investigation was conducted to determine the techno-economic feasibility of applying fabric filter dust collectors to pulverized coal fired boilers. The pilot facility, installed on the slip stream of a 250,000 pph boiler, was capable of handling 9,000 ACFM at an air-to-cloth ratio (A/C) of 6.1. Filter media evaluated included Teflon felt, Teflon woven and woven glass.

Dust removal efficiencies and pressure drop characteristics over a range of air-to-cloth ratios were determined for the three (3) types of filter media.

The installed, operating and annualized costs for fabric filters were developed and compared with the economics of electrostatic precipitators.

TEST PROGRAM

A pilot fabric filter unit was installed on the slip stream of a 250,000 lb./hr. pulverized coal-fired boiler. This boiler supplies both electricity and heat for the campus of a major university in the Great Lakes region. The pilot unit became operational in September, 1977, and a program of study was initiated, included in this program was the screening of a variety of filter media. These included Teflon felt, Style 2363, a 14 oz. woven glass and woven Teflon, Style 0954.

The main purpose of the program was to study varied operation parameters as related to the short-term performance of each filter media:

1. The effect of A/C ration on pressure drop and dust removal efficiency.
2. The determination of cleaning cycles most compatible with each fabric.

The second major objective of this program was to develop and compare the economics of employing these media in a baghouse system with those of an electrostatic precipitator.

A two (2) module Enviro-Clean SD-8 rectangular dust collector was used as the test vehicle. The baghouse is designed to contain a total of 1,660 square feet of cloth. The house is subdivided into twelve (12) cells, each containing twelve (12) bags, giving a total house capacity of 144 bags. Each bag is 8' - 8" long and 5" in diameter, giving 11.5 square feet of cloth per bag. The bags are hung from the tube sheet, locked in place by two snap rings which are sewn into the bag. The bags were secured to a metal grid at the bottom. A metal cage is set inside those bags not containing their own rings to prevent collapse.

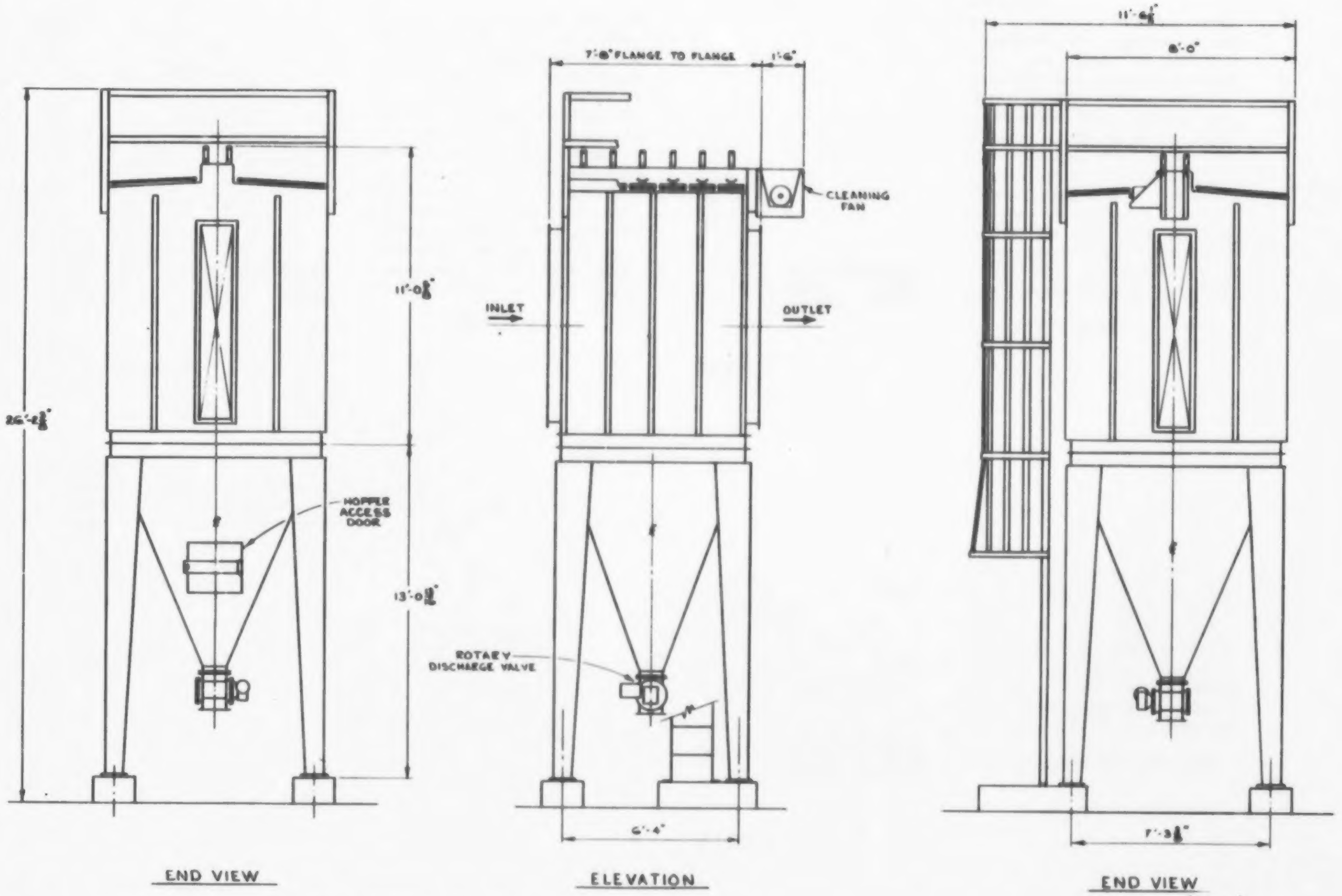
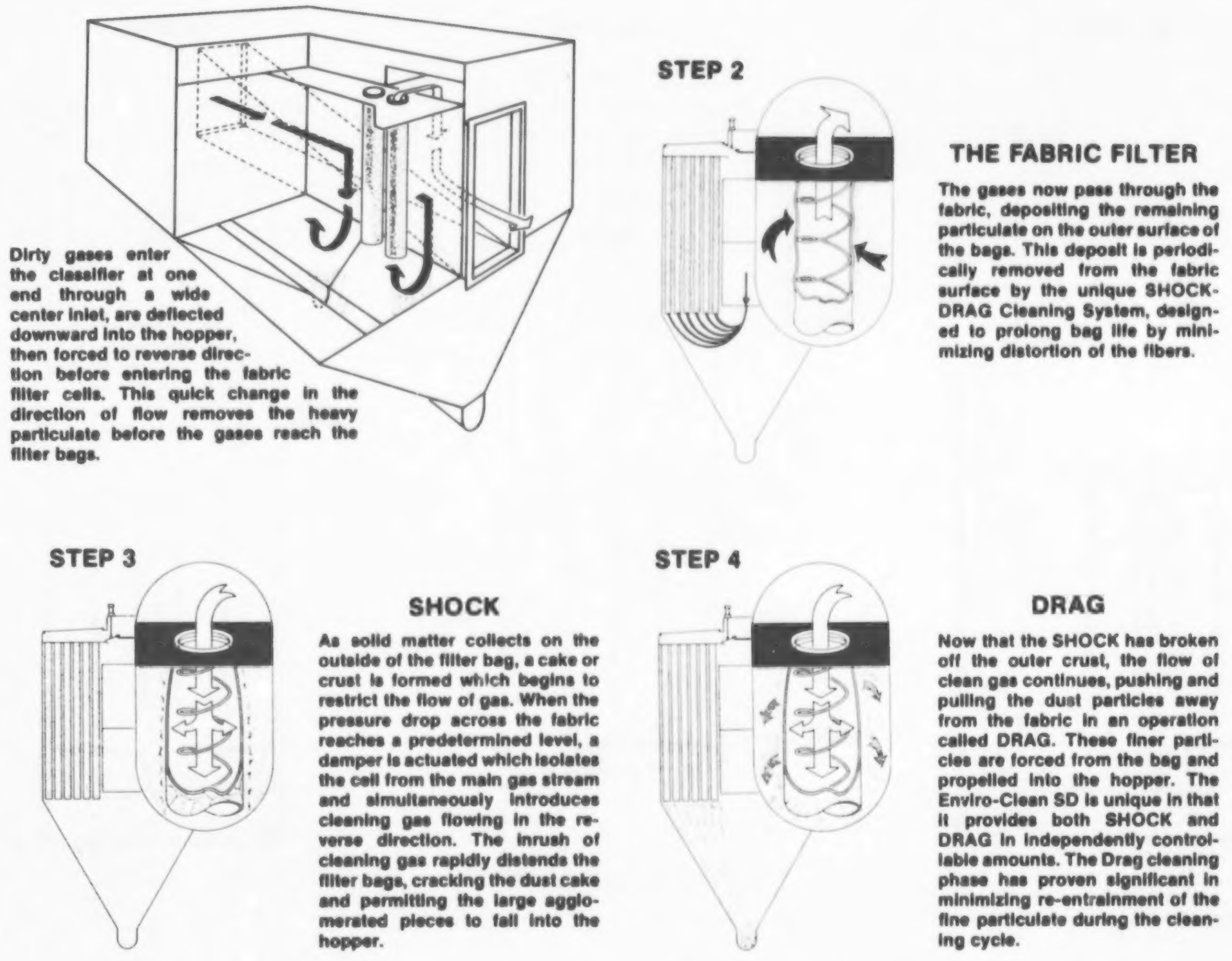

END VIEW
ELEVATION
END VIEW
HOPPER ACCESS DOOR
7'-8" FLANGE TO FLANGE
1'-6"
CLEANING FAN
INLET
OUTLET
ROTARY DISCHARGE VALVE
6'-4"
8'-0"

Figure 1. SCHEMATIC DIAGRAM OF THE ENVIRO-CLEAN DUST COLLECTOR MODEL 144-SD8-5-104



Dirty gases enter the classifier at one end through a wide center inlet, are deflected downward into the hopper, then forced to reverse direction before entering the fabric filter cells. This quick change in the direction of flow removes the heavy particulate before the gases reach the filter bags.

STEP 2

THE FABRIC FILTER

The gases now pass through the fabric, depositing the remaining particulate on the outer surface of the bags. This deposit is periodically removed from the fabric surface by the unique SHOCK-DRAG Cleaning System, designed to prolong bag life by minimizing distortion of the fibers.

STEP 3

SHOCK

As solid matter collects on the outside of the filter bag, a cake or crust is formed which begins to restrict the flow of gas. When the pressure drop across the fabric reaches a predetermined level, a damper is actuated which isolates the cell from the main gas stream and simultaneously introduces cleaning gas flowing in the reverse direction. The inrush of cleaning gas rapidly distends the filter bags, cracking the dust cake and permitting the large agglomerated pieces to fall into the hopper.

STEP 4

DRAG

Now that the SHOCK has broken off the outer crust, the flow of clean gas continues, pushing and pulling the dust particles away from the fabric in an operation called DRAG. These finer particles are forced from the bag and propelled into the hopper. The Enviro-Clean SD is unique in that it provides both SHOCK and DRAG in independently controllable amounts. The Drag cleaning phase has proven significant in minimizing re-entrainment of the fine particulate during the cleaning cycle.

Figure 2. BAGHOUSE PICTORIAL SHOWING GAS FLOW

The operation of the baghouse is as follows: The dirty gases enter one end of the house, pass through the tapered duct, into a classifier then through the bags. The classifier forces the dirty gases to change direction 90° then 180°. This quick directional change forces the larger and heavier particles out of the flow so that they will fall directly into the hopper. Dirty gases enter the classifier through a central tapered duct to feed the same quantity of gas into each cell.

The gases are now forced through the fabric, depositing the remaining particulate on the outside of the bag while the clean gas continues through the center of the filtering bag and into a center exit plenum through an open damper above the tube sheet.

As solid matter collects on the outside of the bag it builds a cake or crust which begins to restrict the flow of gases. The bags are cleaned one cell at a time by closing off the cell damper and at the same time introducing cleaning gas flowing in the reverse direction. The inrush of cleaning gas expands the bag with such a shock that the "cake" is cracked and particulate matter falls off the bag and into the hopper.

Now that the shock has broken off the outer crust, the flow of clean gas continues pushing and pulling the dust particles away from the fabric in an operation called "drag". This phase of the cleaning has proven significant in minimizing the re-entrainment of the fine particulate during the cleaning cycle.

The power plant uses three boilers. Unit 3 is a new 300,000 lb./hr. boiler with a hotside electrostatic precipitator. Both Unit 1 and Unit 2 are 250,000 lb./hr. boilers by Wickes with existing mechanical collectors and cold electrostatic precipitators. Boiler No. 2 was the unit tapped for the pilot plant slip stream. The plant burns pulverized coal of Eastern Kentucky origin. Typical coal analysis shows moisture 6-7%, ash 8%, sulfur 0.75%, BTU of 12,500.

The pilot plant was installed on a one foot square slip stream duct from Boiler No. 2. The duct was connected to the boiler between the air preheater and existing mechanical collector, and included a scoop directed into the flow of the flue gas. After passing through the baghouse, the slip stream flow exited into the clean side of the existing ESP. Both the slip stream duct and the baghouse were insulated.

Damper systems and control arrangements allow for variations of main gas volume, reverse-air volume, duration of cleaning and frequency of cleaning.

Table No. 1 illustrates the baghouse inlet conditions. Gas temperatures averaged 350° F while the gas volumes ranged between 1000 and 4140 ACFM, depending on A/C ratios and the amount of fabric in service. The inlet gas stream contained in the order of 3.7 grains/SCF of fine dry ash.

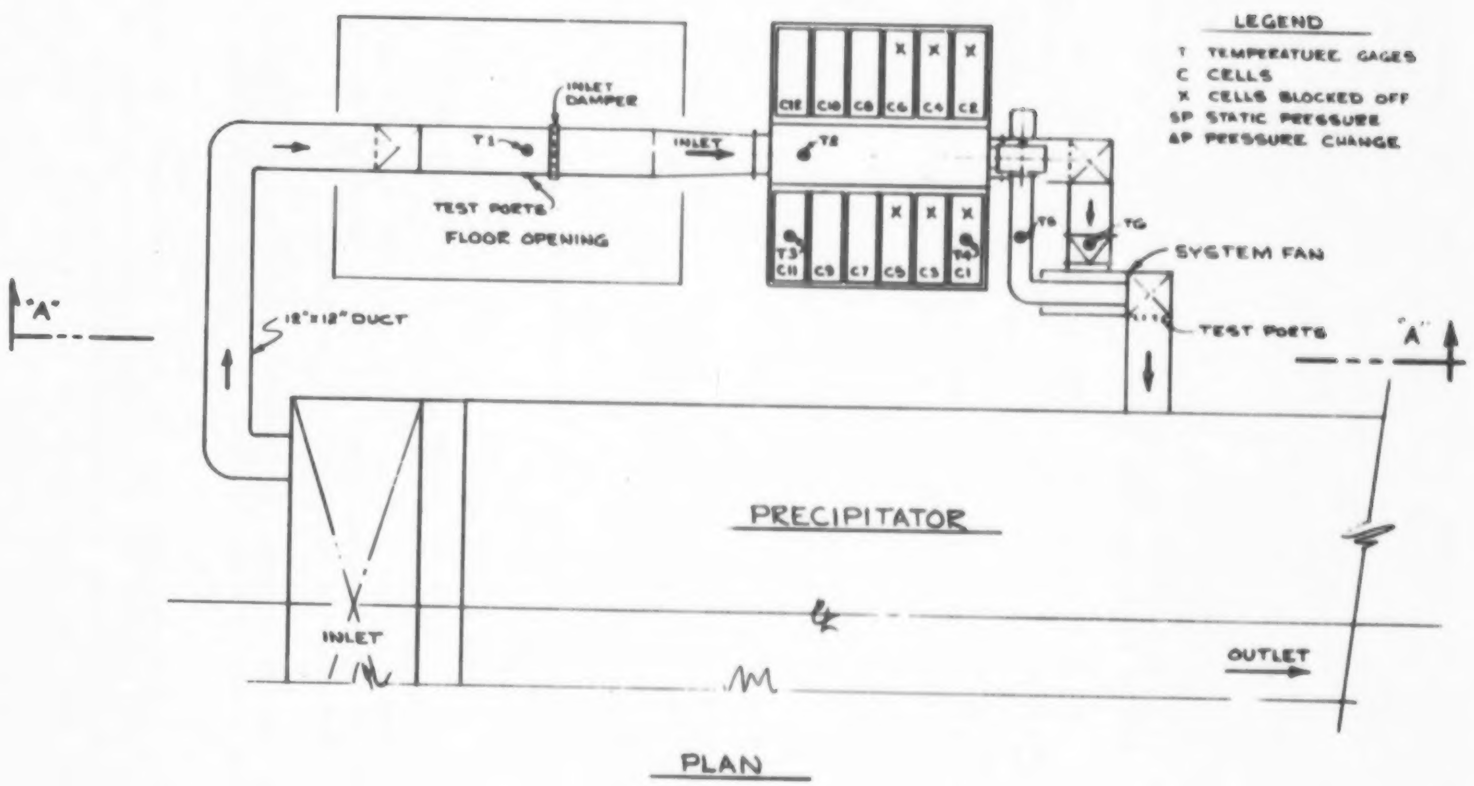

LEGEND
T TEMPERATURE GAGES
C CELLS
X CELLS BLOCKED OFF
SP STATIC PRESSURE
ΔP PRESSURE CHANGE
INLET DAMPER
T1
TEST PORTS
FLOOR OPENING
INLET
T2
C12
C10
C8
C6
C4
C2
X
T3
C11
C9
C7
C5
C3
C1
T4
T5
T6
SYSTEM FAN
TEST PORTS
"A"
"A"
12"×12" DUCT
PRECIPITATOR
INLET
OUTLET
PLAN

Figure 3. DUST COLLECTION SYSTEM - PLAN VIEW

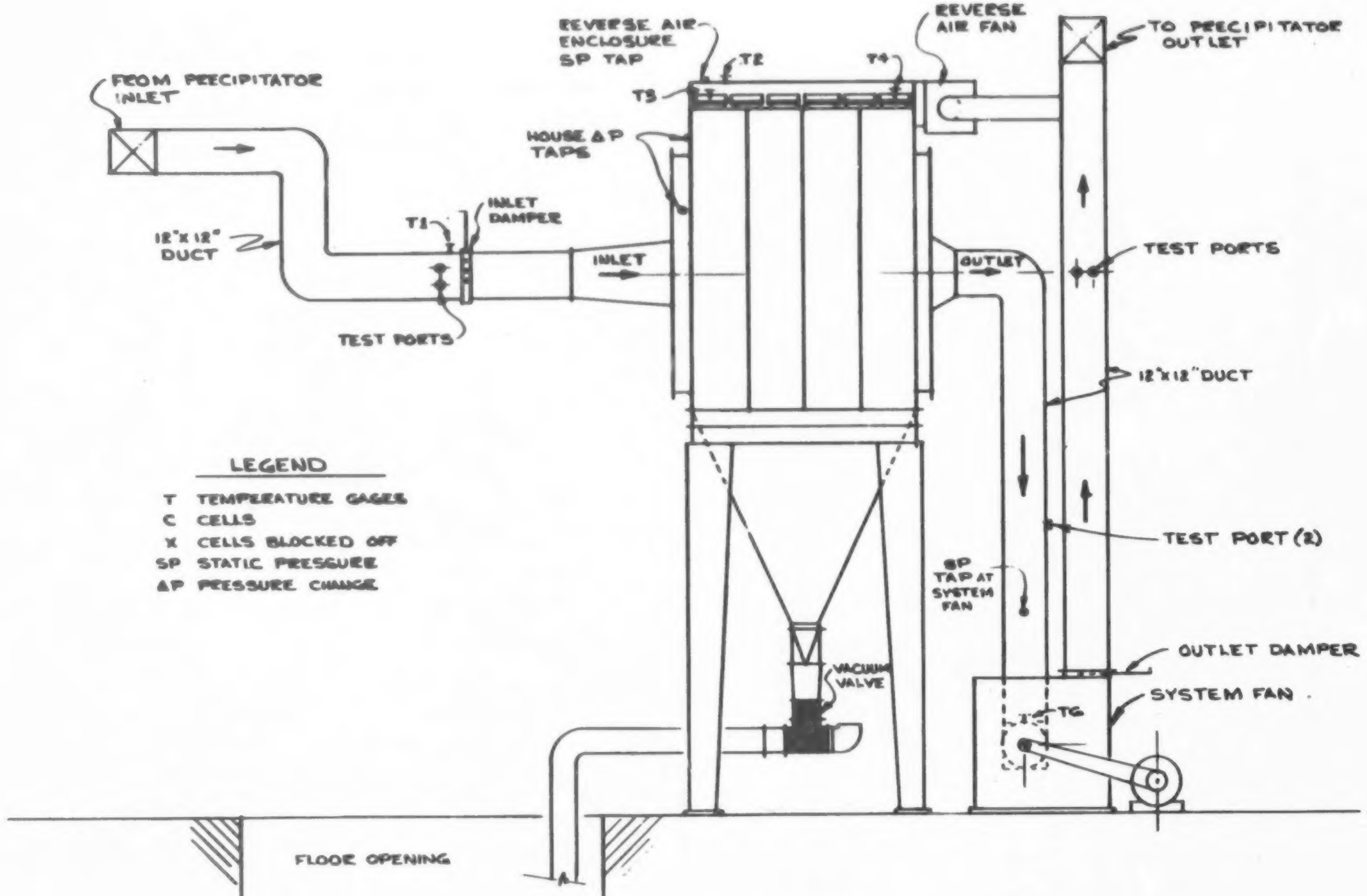

FROM PRECIPITATOR INLET
12"x12" DUCT
T1
INLET DAMPER
TEST PORTS
INLET
HOUSE ΔP TAPS
REVERSE AIR ENCLOSURE SP TAP
T2
T3
T4
REVERSE AIR FAN
TO PRECIPITATOR OUTLET
OUTLET
TEST PORTS
12"x12" DUCT
TEST PORT (2)
SP TAP AT SYSTEM FAN
OUTLET DAMPER
SYSTEM FAN
T6
VACUUM VALVE
FLOOR OPENING
LEGEND
T TEMPERATURE GAGES
C CELLS
X CELLS BLOCKED OFF
SP STATIC PRESSURE
ΔP PRESSURE CHANGE

Figure 4. DUST COLLECTION SYSTEM - GENERAL ARRANGEMENT

Table 1. BAGHOUSE INLET GAS STREAM PROFILE

Gas Temperature	350° F
Stack Rate (ACFM)	1000-4140
Flue Gas Composition	
H_2O (%)	7.5
O_2 (%)	6.0
CO_2 (%)	12.0
Particulate Concentration (Grains/SCFD)	3.6735

Inlet particle sizing is graphically displayed in Figure 5. The data indicated that 60% of the material is less than 10 microns. Subsequent in-situ particle sizing indicate the material to be even finer with as much as 30% two microns or below.

The baghouse outlet dust concentrations apparently were not affected by normal variations in inlet concentrations. However, soot blowing conditions were avoided for all testing. Outlet dust concentrations for all fabrics, although somewhat higher than we would like to see, complied with the state codes.

Thirty-five (35) Teflon woven bags were installed in the house and remained on stream for 500 hours over a three (3) week period, primarily at a 2.5/1 air-to-cloth ratio with a resultant pressure drop steadily around 1.4 inches of water. By the end of 500 hours the bags had only a light film of dust on them. Two hour tests with no reverse-air cleaning were conducted to determine resultant pressure drops versus air-to-cloth ratios. Figure 7 shows that even though resistance did increase with no cleaning, we were able to return to the original Δp with one clean-down cycle.

Sixty (60) 14 oz. woven glass bags were installed in Cells 1 through 6. The bags had metal rings sewn into them to prevent collapse, therefore no rigid cages were needed. The bags were continuously on-stream for 150 hours at air-to-cloth ratios of 2, 4 and 6/1. After 150 hours of operation, no caking was seen on the bags. Once again, although Δp did increase after two hours of no cleaning, a one cycle cleandown was all that was necessary to return to normal operational pressure drops.

Forty-eight (48) Teflon felt bags, Style 2363, were installed and remained on stream for 600 hours. During this time the baghouse was brought on stream cold nine (9) times so that significant acid dew point excursions are suspected. After 600 hours of operation, the bags were heavily caked. Figure 8 shows that the Δp, as in the case of the other fabrics, did increase with no cleaning for a two hour period. However, at the highest air-to-cloth level, we did encounter some difficulty in returning to normal operating pressures with one clean-down cycle.

Comparisons of normal operating pressure drops for the fabrics tested over the range of air-to-cloth ratios studied are presented in Figure 10. Teflon woven operated at the lower values while Teflon felt normally was the highest, with both exhibiting a gradual increase in pressure drop with increasing air-to-cloth ratios. Pressure drop values for woven glass increased rapidly above a 4 to 1 air-to-cloth ratio.

The economics of applying fabric filters to pulverized coal boilers were evaluated and compared with those for an electrostatic precipitator (ESP). Installed costs were calculated for a fabric filter dust collector sized to handle 150,000 ACFM at 400° F. The costs were developed for three (3) filter media tested. Air-to-cloth ratios considered were 2, 4,

Figure 5. INLET PARTICLE SIZE DISTRIBUTION
LAB DETERMINATION

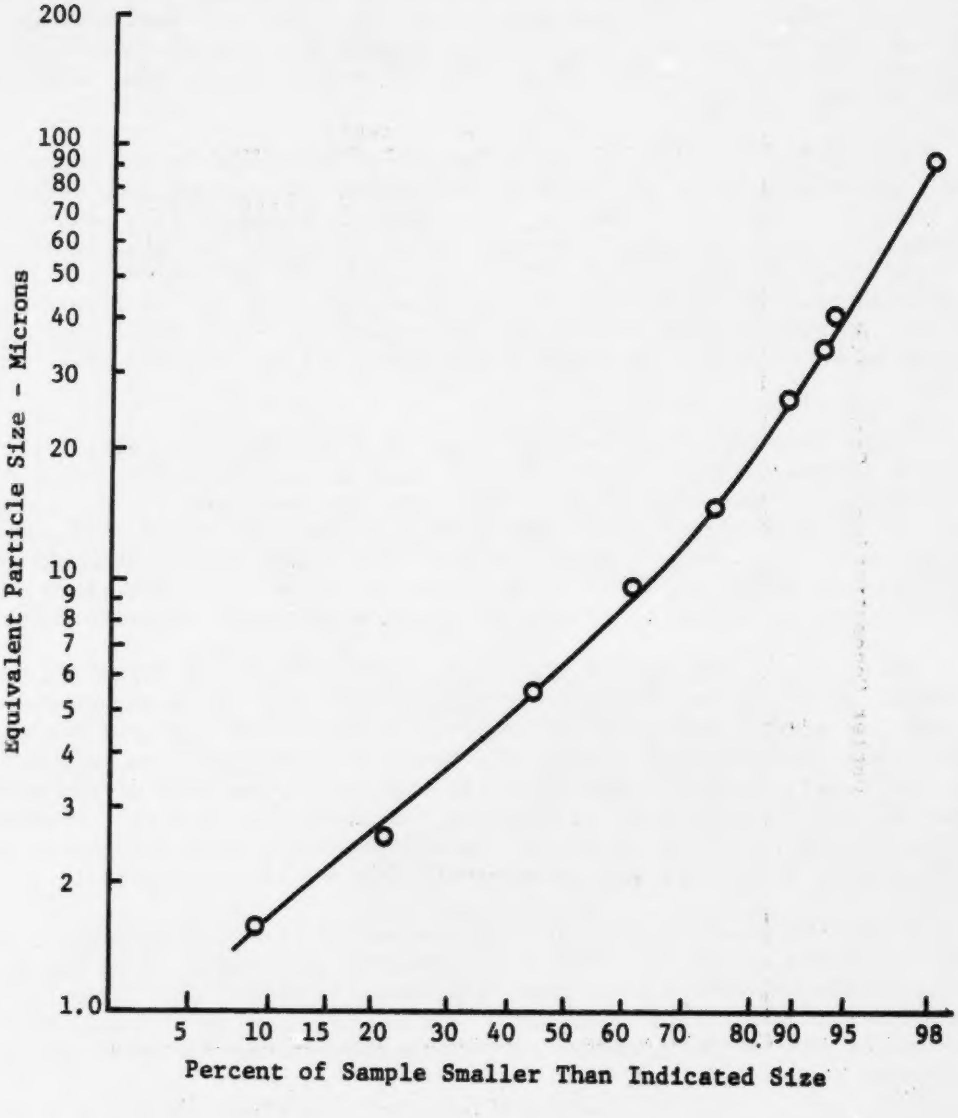


Figure 6. OUTLET CONCENTRATION
VS.
AIR-TO-CLOTH RATIO

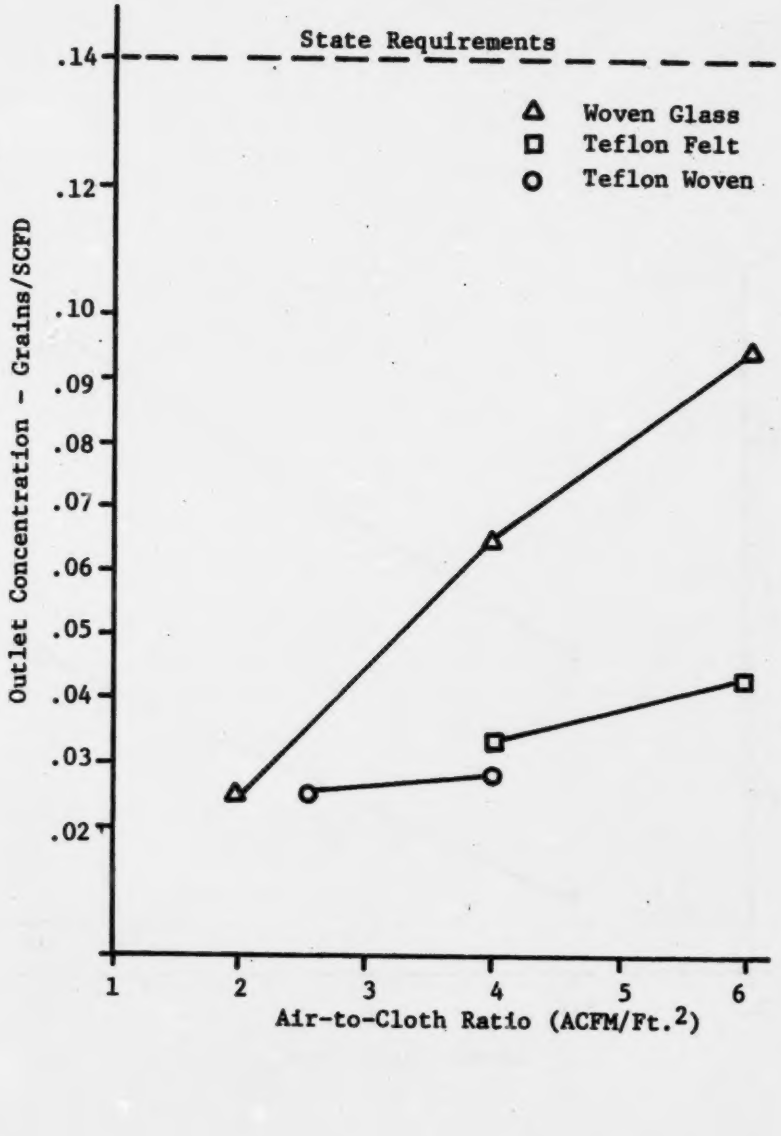


Figure 7. PRESSURE DROP ACROSS BAGS
VS.
AIR-TO-CLOTH RATIO

Case: Teflon Woven

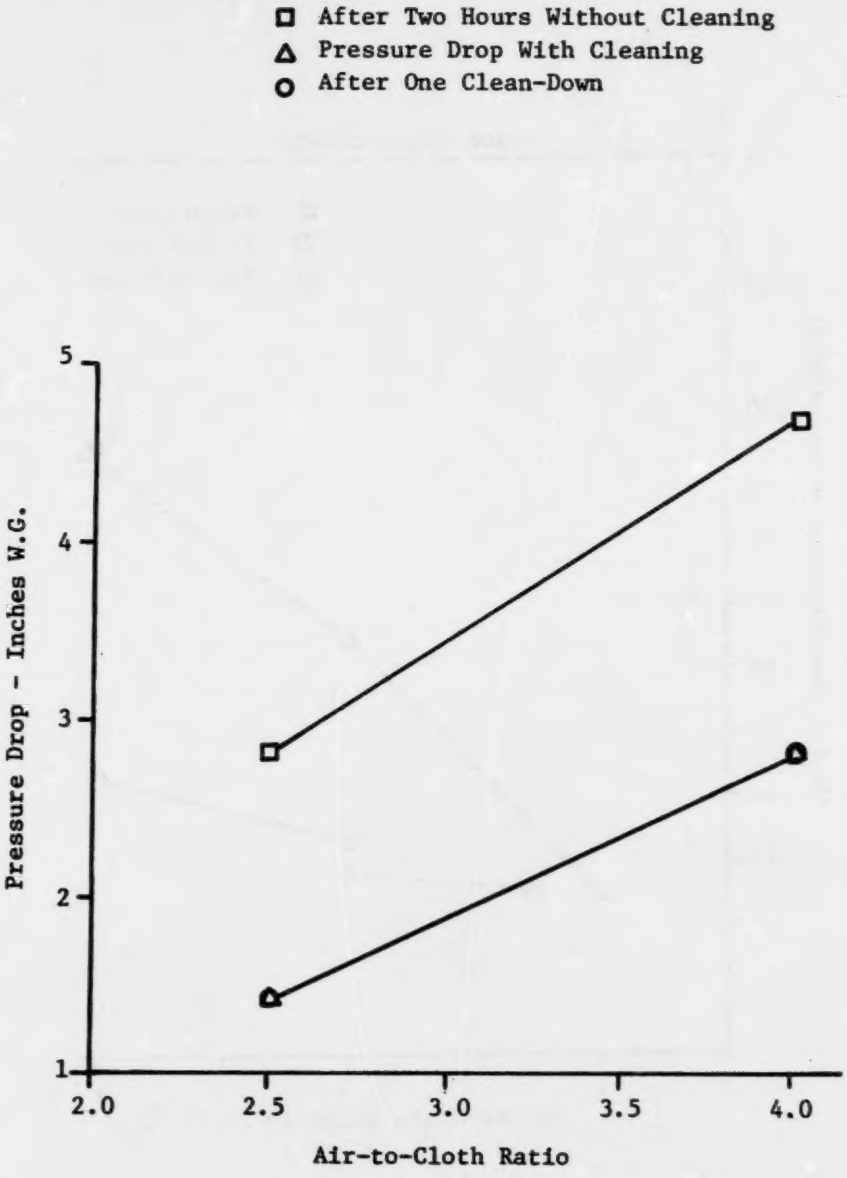


Figure 8. AIR-TO-CLOTH RATIO

Case: Woven Glass

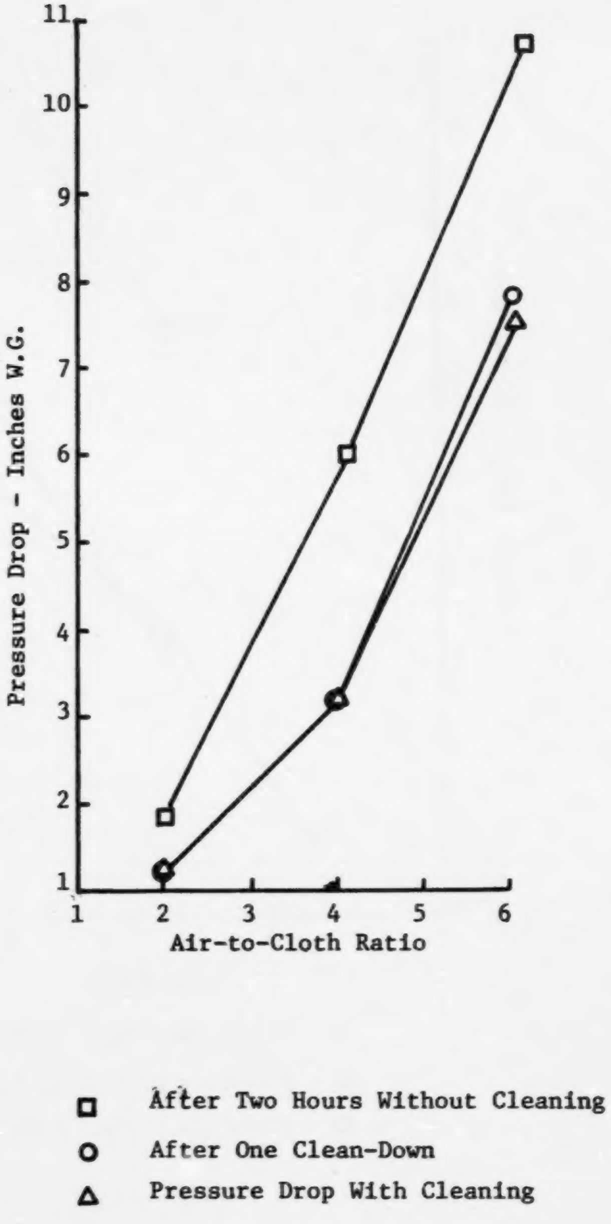


Figure 9. PRESSURE DROP ACROSS BAGS
VS.
AIR-TO-CLOTH RATIO

Case: Teflon Felt

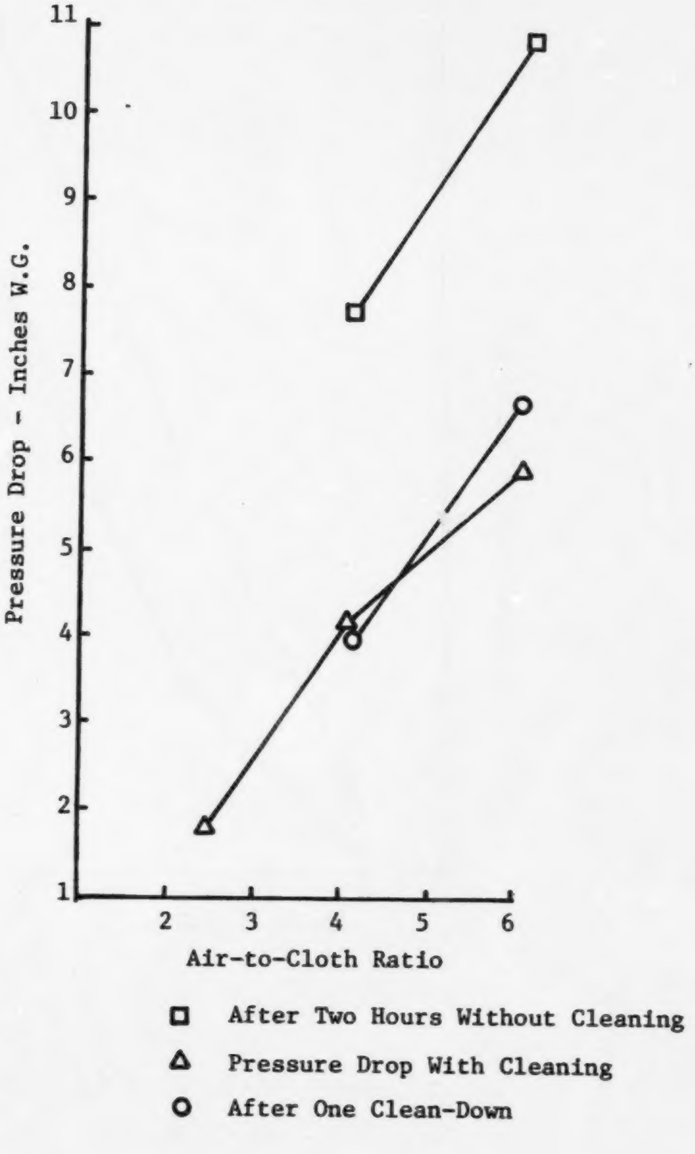
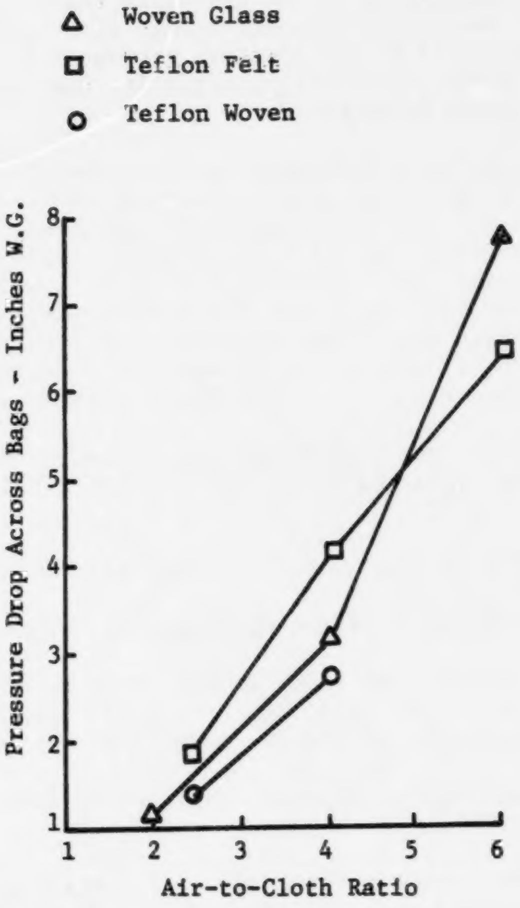


Figure 10. COMPARISON OF OPERATING PRESSURE DROPS
VS.
AIR-TO-CLOTH RATIO



and 6. Table 2 shows he cost of the bags as a percentage of installed costs. These costs were developed from actual bag manufacturer quotes obtained during 1978.

The installed costs for an electrostatic precipitator capable of handling 150,000 ACFM at 99.8% efficiency were also developed. This cost was developed by adding the flange-to-flange cost (supplied by a leading ESP manufacturer) plus 70% of the purchase price for erection cost (the same figure was used in the fabric filter case).

A graphical comparison of the installed costs for the three (3) bag materials versus the installed costs of the electrostatic precipitator is shown in Figure 11. At air-to-cloth ratios of 4.5 or greater, the installed costs of the fabric filter (for all bags considered) was lower than the electrostatic precipitator.

Operating costs were developed for the fabric filters with two and four year bag life and compared with those of the electrostatic precipitator. Fabric filter costs were based on the actual pressure drops observed for each fabric at the different air-to-cloth ratios. Precipitator costs were based on a pressure drop of 2.5" W.G. (All pressure drop values included 2.0" W.G. for drop across the inlet duct.) Electrical rates for both cases were assumed to be $.03/KWH. The costs presented in Figure 12 show the electrostatic precipitator to be less expensive to operate than any of the fabric filter cases considered.

While studying these graphs one must remember that in the formula for calculating annual operating costs for a specific bag life only two variables exist:

1. The number of bags (which decrease with increasing A/C).

2. The pressure drop (which increases with increasing A/C).

It appears that at some point in the increase of the air-to-cloth ratio for a particular bag life, the effect of the increase in pressure drop outweighs the effect of the decrease in number of bags required.

All Δp values were those seen or projected from normal circumstance in the test program.

The annualized costs or total costs of control were developed from the preceding installed and operating costs. These results as shown here were based on the following assumptions: First, hardware and installation costs are depreciated over fifteen (15) years. Second, the straight line method of depreciation (6 2/3% per year) is used. This method has the simplicity of a constant annual write-off. Third, costs called capital charges, which include interest, taxes, insurance and other miscellaneous costs are assumed equal to the amount of depreciation, or 6 2/3% of the initial installed costs.

Table 2. BAG COST AS A PERCENT OF INSTALLED COST

Filter Media	Installed Cost	Bag Cost	% of Installed Cost For Bags
Woven Glass			
2/1	1,387,530	97,200	7.0
4/1	784,900	51,840	6.6
6/1	538,860	34,560	6.4
Teflon Felt			
2/1	1,568,970	343,440	21.9
4/1	881,668	183,168	20.8
6/1	626,412	122,112	19.5
Teflon Woven			
2/1	1,400,490	174,960	12.5
4/1	791,812	93,312	11.8
6/1	566,508	62,208	11.0

Figure 11. INSTALLED COSTS
VS.
AIR-TO-CLOTH RATIOS

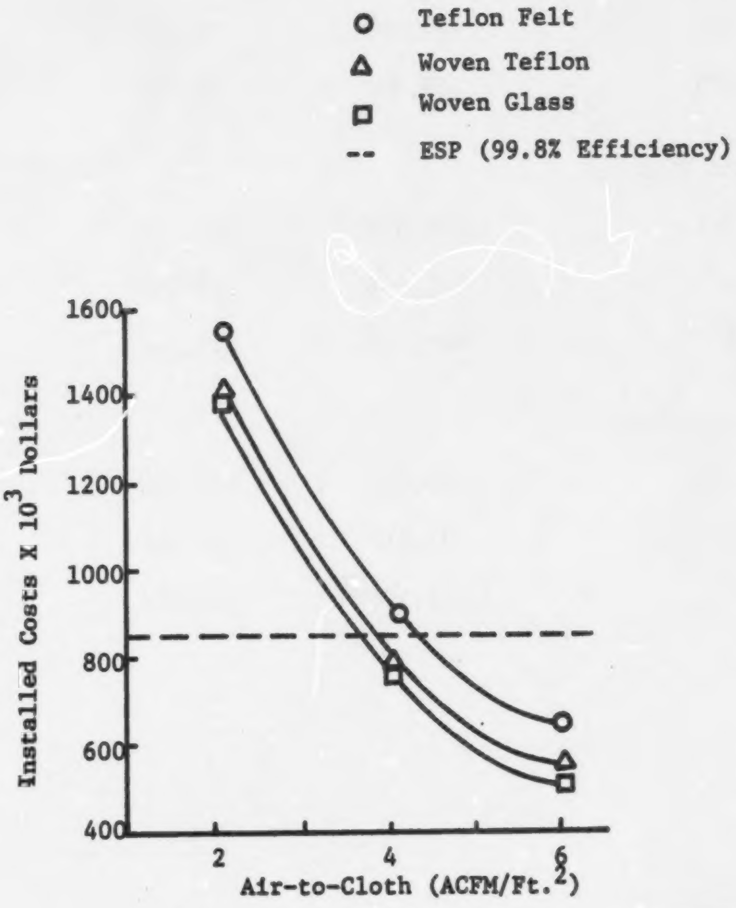


Figure 12. ANNUAL OPERATING COSTS
VS.
AIR-TO-CLOTH RATIO
(2 Year Bag Life)

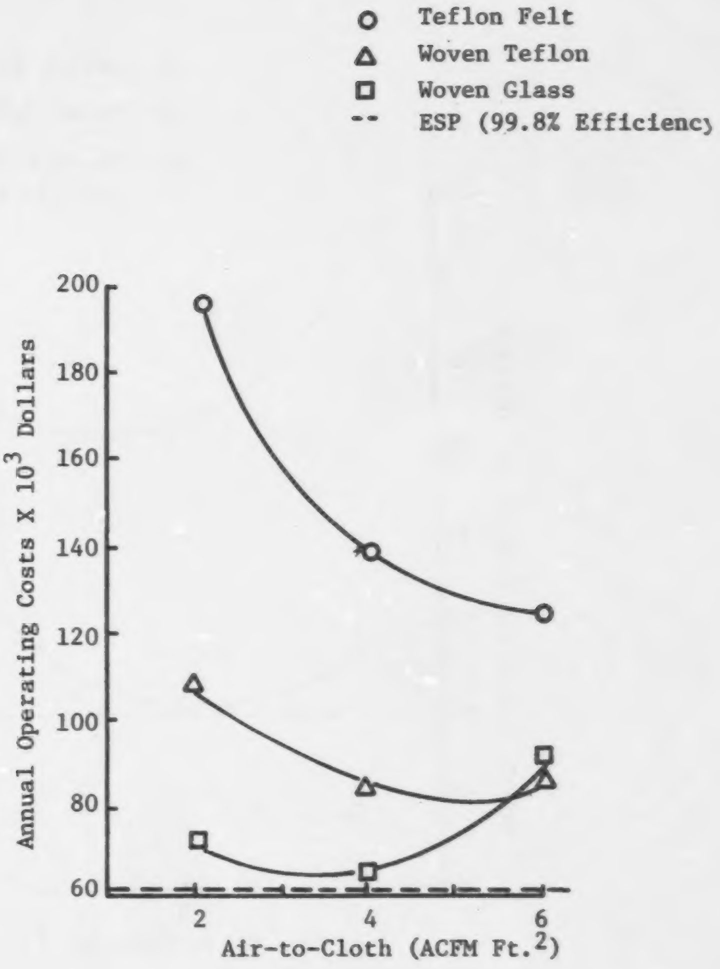


Figure 13. ANNUAL OPERATING COSTS
VS.
AIR-TO-CLOTH RATIO
(4 Year Bag Life)

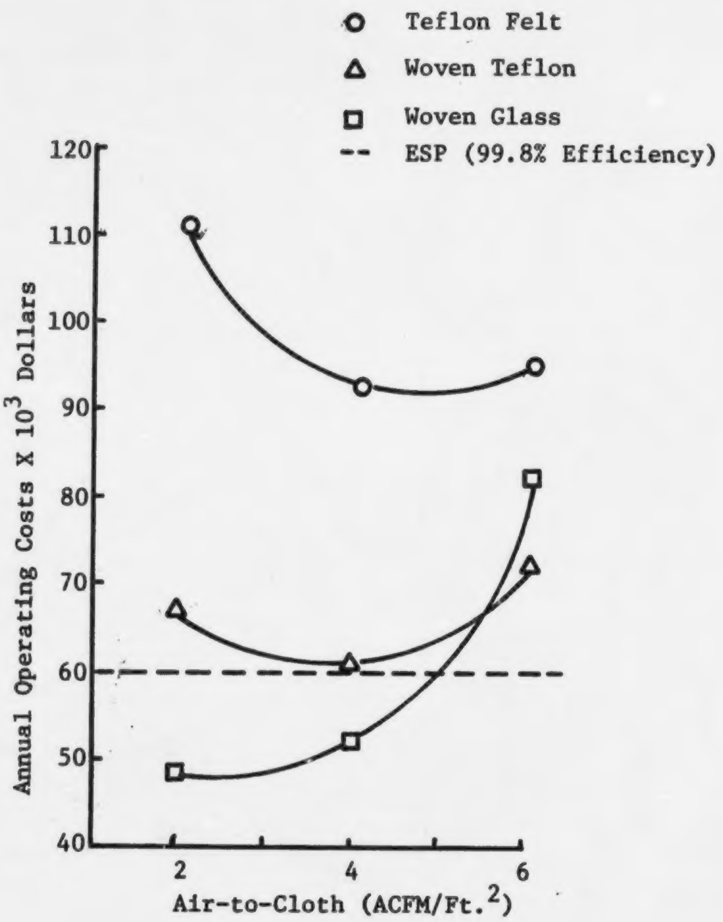


Figure 14. TOTAL ANNUALIZED COSTS
VS.
AIR-TO-CLOTH RATIO
(2 Year Bag Life)

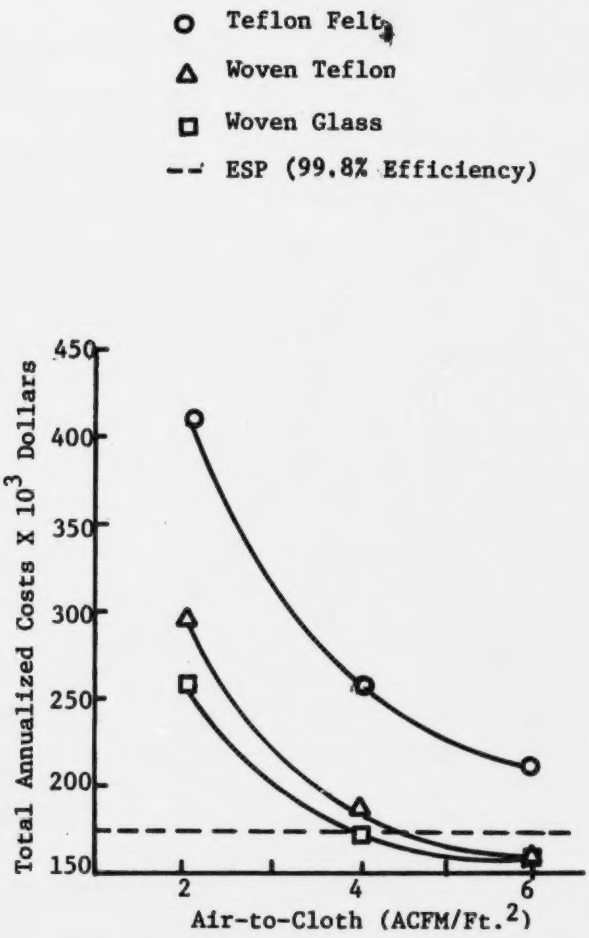
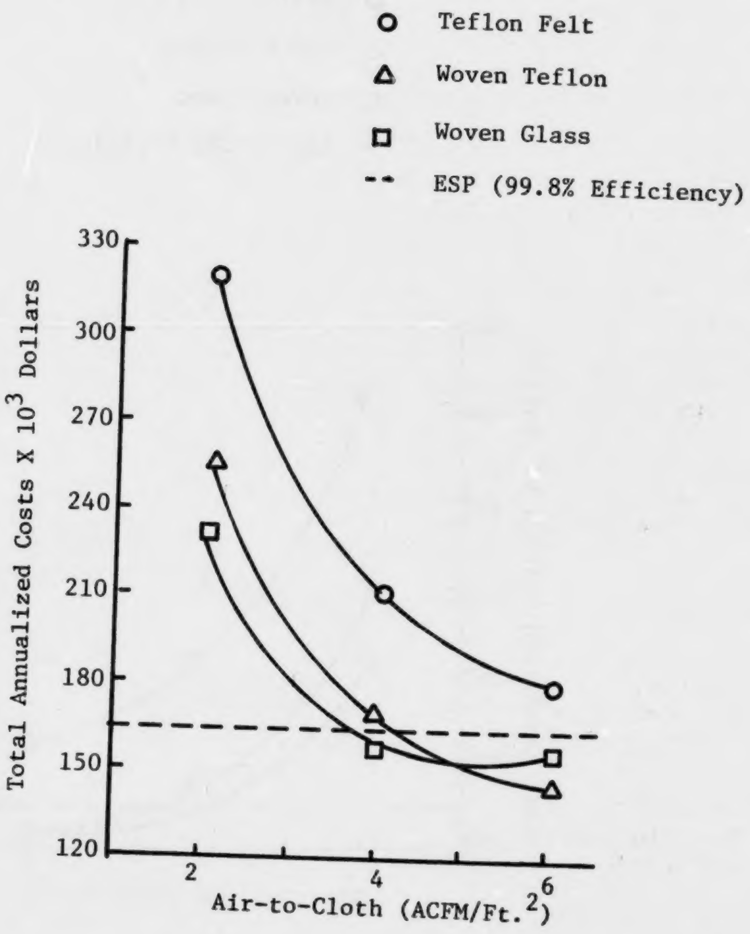


Figure 15. TOTAL ANNUALIZED COSTS
VS.
AIR-TO-CLOTH RATIO
(4 Year Bag Life)



As illustrated in Figures 14 and 15, the baghouse employing either of the woven materials at an air-to-cloth ratio of 4 to 1 or greater and electrostatic precipitators are extremely competitive on an annualized cost basis.

CONCLUSIONS

1. The three filter media tested did not show signs of wear or weakening during this test program. However, on-stream time was very limited.

2. The pressure drops obtained for the three filter media were normally within the commercially acceptable range.

3. Only in the woven glass case was a clear correlation between filtration velocity and outlet dust concentration in evidence. The other two materials may well have such a correlation, but it was not clearly demonstrated in this program.

4. Economic analysis indicate that the annualized costs of the electrostatic precipitator and the fabric filter are very close and perhaps even favor the ESP. This is very interesting when one considers that we performed the same analysis on a small stoker fired boiler, with the results being strongly in favor of a baghouse.

I think that this further demonstrated what many others have been saying, that final selection of the best alternative can only be made after each boiler case has been considered individually.

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(1) McKenna, J. D., Mycock, J. C. and Lipscomb, W. O., "Performance and Cost Comparisons Between Fabric Filters and Alternate Particulate Control Techniques", JAPCA, V 24, N 12, December 1974, p. 1144.

(2) Edminsten, N. C. and Bunyard, F. L., "A Systematic Procedure for Determining the Cost of Controlling Particulate Emissions from Industrial Sources", JAPCA, V 20, N 7, p. 446 (1970).

APPLICATION OF SLIP-STREAMED AIR POLLUTION CONTROL DEVICES ON WASTE-AS-FUEL PROCESSES

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ABSTRACT

The recovery of energy from the combustion of municipal solid wastes is becoming an attractive alternative as landfill space becomes scarce and the availability of fossil fuels decreases. However, particulate emissions from these "waste-as-fuel" processes have been found to have significantly different chemical and physical properties than when firing coal only. Such differences can affect the design and operation of air pollution control equipment. Presented in this paper is a state-of-the-art technology assessment of various air pollution control devices for use in controlling waste-as-fuel emissions, as well as an overview of PEDCo Environmental's current program for the design, fabrication, and slip-streaming of pilot-scale emission control devices at various waste-as-fuel installations.

The rationale for choosing a fabric filter as PEDCo Environmental's primary pilot device will be discussed along with the approach utilized in design, fabrication, and operation. The unit will be designed with sufficient flexibility for testing at a co-fired boiler operation (coal plus refuse) and in a refuse preprocessing plant, as well as suitable for slip-streaming at a mass burn incineration site. A physical layout of the initial test site will be presented including an outline of the actual test program and anticipated results. The program will also address certain pretreatment elements along with finetuning recommendations/modifications for enhancing existing boiler or air pollution control equipment performance.

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Introduction

PEDCo Environmental, Inc., Cincinnati, Ohio, is currently engaged in an EPA-sponsored contract whose goal is to develop prototype pilot scale air pollution control devices that can be tested and evaluated on various waste-as-fuel processes to control potentially harmful air emissions. The duration of the study is 36 months, and is phased as follows: 1) Collection of data on known and potential air pollutants produced from waste-as-fuel processes, 2) Assessment of air pollution control technology for waste-as-fuel processes, 3) Determination of the best air pollution control devices and development of conceptual devices for pilot-scale air pollution control devices for the most significant problems associated with waste-as-fuel processes, 4) Procurement of two to four pilot-scale air pollution control devices, and 5) Operation of the pilot-scale units to generate and analyze data.

Midwest Research Institute (MRI) is concurrently conducting a comprehensive environmental assessment of various resource recovery operations for EPA; data from this project will provide valuable technical direction for the PEDCo study. Presented herein is a state-of-the-art assessment of air pollution control technologies for waste-as-fuel processes, and a status report on the PEDCo project.

Preliminary Program

The nature and magnitude of atmospheric pollutant emissions resulting from the thermal conversion of waste-to-energy are still somewhat of an unknown, as are the requirements for emission control technology. Table 1 summarizes the ranges of flue gas characteristics that potentially could be emitted from the three generic waste-as-fuel processes: co-firing, mass burn incineration, and pyrolysis.

Table 1. TYPICAL FLUE GAS ANALYSIS

Emission	Range
Particulate[a]	0.56 to 2.30 gains per actual cubic ft.
SO_2	1,500 to 2,100 parts per million
NO_x	60 to 100 parts per million
Chloride (Cl^-)	100 to 1000 parts per million

[a] Particle size distribution curve is shown in Figure 1.

The concurrent MRI study involves source testing various generic waste-as-fuel technologies to quantify the magnitude of these emissions.

The focal point of this study will be the combustion process. Pyrolysis is actually a fuel preparation step, wherein the resultant gas or oil is sufficiently cleaned in-process so that upon combustion in a boiler, little or no air emissions problems should result. Therefore, it will not be of primary interest in this project.

Particulate emissions are one of the most apparent problems associated with combusting RDF, especially for a co-fired process. This is due in part to the higher ash content of the RDF versus coal, as well as the greater difficulty in maintaining pollution control device efficiencies due to the increased excess air requirements to combust RDF optimally. The presence of RDF in a co-fired operation with coal appears to have little or no effect on the uncontrolled particle size distribution curves as shown on Figure 1, and as also indicated by other available data (Ref. 2).

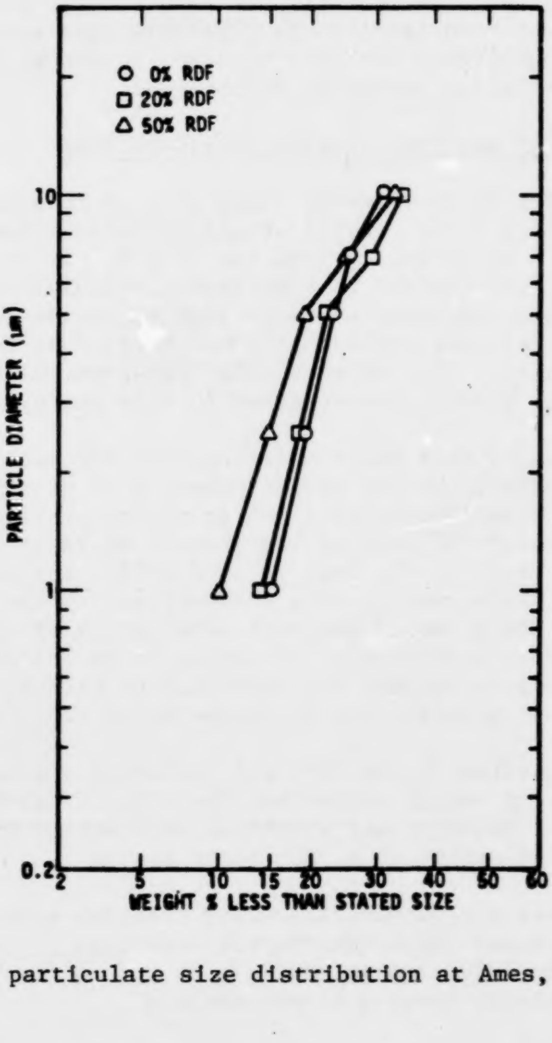

Figure 1. Stack particulate size distribution at Ames, Iowa (Ref. 2.)

There logically should be an increase in uncontrolled particulate emissions when co-firing RDF and coal versus coal-firing along. However, source tests at Ames and Wright-Patterson AFD actually showed a decrease in particulate emissions based on a gram per megajoule basis (Ref. 2). Gaseous chloride, most likely in the form of HCL, increases significantly over coal, and SO_2 emissions typically decrease (although St. Louis data indicated an increase) when co-firing RDF and coal. Heavy metals were analyzed in the co-fired fly ash, and calcium, copper, iron, lead, and zinc showed significant increases.

From the air pollution control technology standpoint, emissions from co-firing and mass burn incineration appear to be the most difficult to control. Control device inlet temperatures may be as high as 600°F (316°C) with inlet grain loadings of 1.2 to 2.4 gr/dscf (2.6 to 5.3×10^3 mg/Nm^3) and in contrast to fly ash from coal, co-fired fly ash resistivity may change which can affect the operation of an ESP. The design of emissions control equipment at each facility is generally site specific, with some in-process (and combustion) analysis required to assure that optimal operation of the existing equipment is obtained.

Fabric Filter Design and Test Program Considerations

The focal point of the current study will be to attempt to use state-of-the-art technologies for control of air emissions from co-combustion of coal and RDF. More specifically, the use of a fabric filter as a primary control device for the removal of submicron particulate will be studied. Wet scrubbers, while cognizant of their high corrosion potential and associated water treatment costs, might be utilized to control a gaseous HCl pollutant problem. The use of an ESP, for particulate control from co-fired boilers, will also be investigated in this study.

It is anticipated that EPA's existing IERL-RTP mobile air pollution control devices, namely the ESP and scrubber, will be utilized in conjunction with PEDCo Environmental's fabric filter evaluation. The mobile ESP has been scheduled for part of the program by early 1979, and the mobile scrubber perhaps in the late Fall of 1978. The mobile ESP should provide key particulate removal data for contrast to the fabric filter operation, the scrubber should generate data on its effectiveness for HCl removal. Both may be used singly, in series or in parallel with existing on-site control devices or with the pilot fabric filter. The EPA's mobile fabric filter is not adequate for the purposes of this program.

Once the evaluation of the IERL-RTP equipment was complete, PEDCo initiated preliminary design activities for a pilot fabric filter. The following technical requirements are based on a design that should generate operational data indicative of a full scale system.

- Reverse air/mechanical shaker cleaning method
- Continuous and uninterrupted operation
- Handle 3000 acfm at 400°F
- Contain at least 3 compartments

- Provide an air to cloth ratio of 2.0 acfm/ft^2 with all compartments on line
- Capable of withstanding temperature excursions up to 500°F
- Leakage of air into the unit less than 50 scfm
- Minimal heat loss through insulation and hopper heaters

The application of a pulse-jet fabric filter may be considered later in the project. However, a reverse air/mechanical shake type of unit is felt to be the current trend for particulate control on coal-fired boilers. A pulse jet collector would be particularly applicable if dust control in RDF preprocessing is considered.

The test program that has been developed surrounding the use of the pilot fabric filter is based on a number of design and operational variables. These variables will be used to evaluate the engineering aspects of the use of fabric filtration in this application, in sufficient detail to provide accurate design of full scale systems. Two of these variables are established by the nature of the waste gas stream. It has been assumed that any full scale installation of a filter must operate with 1) varying flue gas temperatures and 2) fluctuating flue gas compositions, that will be encountered from a coal and RDF-fired boiler or mass burn incinerator operation (See Table 1). The experimental plan developed here is therefore designed to monitor and measure these two factors, but not modify or control them. Equipment start-up temperature will be somewhat controlled with start-up and hopper heaters, but the attempt will be made to operate and test the unit without the heaters operating.

At a constant flow rate, six (6) other variables influence the design and/or operation of a fabric filter:

- Type of filter cloth
- Method of cloth cleaning
- Air-to-cloth ratio
- Degree of cleaning
- Frequency of cleaning
- Total on-stream of fabric

To develop the degree and frequency of cleaning variables, preliminary testing is necessary to determine a "basis" pressure drop across the filter. Degree and frequency of cleaning are then determined by multiplying the basis pressure drop by appropriate factors to be considered in each test. These two variables are considered the most difficult to control and may therefore be dropped from the actual test program.

The detailed operational test matrices for EPA's mobile ESP and scrubber have yet to be developed. The sampling and analytical description for the fabric filter that is to follow, is expected to apply to both of these pilot units. The scrubber will most likely not be investigated for particulate removal efficiency.

Once the operational test matrix is developed, a detailed sampling and analytical program will be implemented. A preliminary flowsheet of this phase of activity is shown in Figure 2. The main objective of this part of the study is to determine particulate loading, particle size, distribution, heavy metals (namely Pb, Ca, Zn, Fe, Be, Ba, Br, and Hg) and chloride concentrations at various points in the system. Other priority pollutants, namely NO_x, SO_2, HC, CO, will also be measured at the outlet of the pilot device.

Test Site Considerations

The potential success of the current study lies in not only the design, procurement, operation, and monitoring of appropriate air pollution control devices, but also slip-streaming and testing at appropriate wastes-as-fuel facilities to generate necessary control data. Site selection and negotiation is very important, and Table 2 delineates more fully those factors necessary for obtaining the proper location for testing. Early in the project, site visits were conducted across several generic technologies as a prelude to a later, more extensive site selection. Table 3 summarizes those site visits conducted to-date by the project team.

Table 2. SITE CONSIDERATIONS FOR CANDIDATE FACILITIES FOR TEST PROGRAM EVALUATION

- Anticipated cooperation from facility management.
- Cooperation from facility unions. Flexibility in operating equipment, working hours, etc.
- Ability to assure that the testing will not disrupt daily operations and commitments, such as waste reduction or steam production.
- Type of generic technology: co-firing, mass incineration, pyrolysis, other.
- Availability of skilled maintenance personnel at the site.
- Anticipated cost of conducting the program at the site.
- Anticipated reproducibility of the emission(s) characteristics.
- Extent of facility modifications required.
- Working conditions (e.g., noise, housekeeping).
- Reliability of waste-as-fuel process operation.
- Safety.
- Availability of utilities on site.

The test site investigations culminated with the selection of Ames, Iowa as the primary choice for field testing of the pilot device. The selection was made for a number of reasons, but is basically attractive because of the wealth of Ames data that is available for comparative purposes and the cooperative spirits among Ames, Iowa State University, U.S. EPA, Department of Energy, and Iowa Department of Environmental Quality personnel. Actual start up of the pilot unit is scheduled for late October of this year.

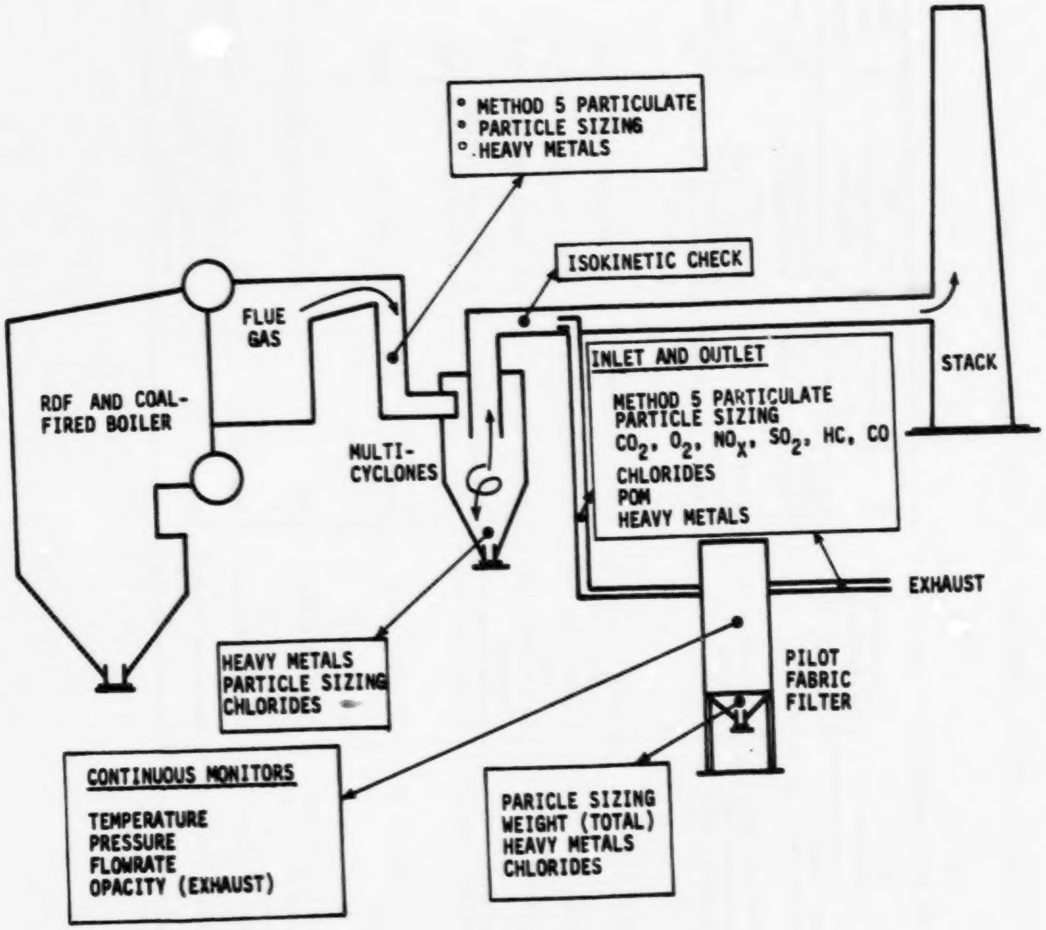
• METHOD 5 PARTICULATE
• PARTICLE SIZING
∘.HEAVY METALS
ISOKINETIC CHECK
FLUE GAS
RDF AND COAL-FIRED BOILER
MULTI-CYCLONES
INLET AND OUTLET
METHOD 5 PARTICULATE
PARTICLE SIZING
CO_2, O_2, NO_X, SO_2, HC, CO
CHLORIDES
POM
HEAVY METALS
STACK
EXHAUST
HEAVY METALS
PARTICLE SIZING
CHLORIDES
PILOT FABRIC FILTER
CONTINUOUS MONITORS
TEMPERATURE
PRESSURE
FLOWRATE
OPACITY (EXHAUST)
PARICLE SIZING
WEIGHT (TOTAL)
HEAVY METALS
CHLORIDES

Figure 2. Proposed sampling and analytical flowsheet for the pilot fabric filter

Table 3. PEDCo RESOURCE RECOVERY SITE VISIT SUMMARY

Generic technology	Plant location	Preprocessing product	Preprocessing emissions control	RDF combustion equipment	Combustion emission control device
Co-firing	Ames, Iowa	Fluff	None	Stoker-boiler	Cyclones
	Chicago SW	Fluff	Baghouse system	Pulverized coal boiler	ESP
	Columbus, Ohio	Shredded waste	None	Stoker-boiler	Cyclone
	Hagerstown, Md.	Pellets	None	Stoker-boiler	Cyclone
	Milwaukee, Wis.	Fluff	Baghouse system	Pulverized coal boiler	ESP
Mass burn	Chicago NW	Bulky items removed	Not applicable	Incinerator/boiler	ESP
	Harrisburg, Pa.	Bulky items removed	Not applicable	Incinerator/boiler	ESP
	Nashville, Tenn.	Bulky items removed	Not applicable	Incinerator/boiler	ESP
	Saugus, Mass.	As received refuse	Not applicable	Incinerator/boiler	ESP
	Hamilton, Ontario	Pulverized refuse	None	Incinerator/boiler	ESP
Pyrolysis	South Charleston, W. Va.	Shredded waste	None	Open burner	None
Other	Fairmont, Minn. (planned late 1978 startup)	Shredded waste	None	Incinerator/boiler	Wet scrubber
	Houston, Texas	Shredded waste	Baghouse	Cement kiln (co-fired with gas)	Wet scrubber
	Minneapolis, Minn.	Dewatered sludge	None	Multi-hearth sludge incinerator	None

Ideally, the stoker-fired boiler No. 5 would be slipstreamed first because of the convenient physical layout in and around the boiler house. Later, a move to boiler No. 7 would gather data on suspension co-firing, as well as comparative performance of a full scale ESP and the pilot fabric filter.

CONCLUSION

When the current study is completed, the technology assessment and subsequent field study analysis should contribute significantly to the data bank of knowledge related to analytical definition and technical control of atmospheric emissions from various waste-as-fuel processes. While primarily focusing on the combustion operation, information on the design and operation of new and retrofit installations of air pollution control equipment at RDF burning facilities will be provided. Later test programs may involve enhancing existing air pollution control equipment performance, as well as consider other emission sources in the waste-as-fuel process.

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ASSESSMENT OF THE COST AND PERFORMANCE OF PARTICULATE CONTROL DEVICES FOR LOW-SULFUR WESTERN COALS

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INTRODUCTION

Teknekron's Energy and Environmental Engineering Division is performing an EPA-funded study to assess the cost and performance of particulate control devices for boilers firing low-sulfur western coal. The primary objective of the study is to provide guidelines to help utility engineers and enforcement personnel select particulate control strategies that will enable such boilers to meet various emission limits. Various control devices are being evaluated for utility boilers of 200 MW or greater and for industrial boilers of less than 25 MW.

Performance and cost models for fabric filters, hot-side and cold-side electrostatic precipitators (ESPs), wet scrubbers, and series ESP/wet scrubber systems are being developed and combined. It is expected that these models will make it possible to select the most economical particulate control strategy for any given application. Furthermore, Teknekron is evaluating the probable impact of ongoing research and development and of new regulations for solid residues and emissions to water and air. One important consideration is the proposed revision of the New Source Performance Standard for sulfur dioxide emissions wherein a fixed percentage of the SO_2 must be removed. In light of this standard, which will require flue gas desulfurization (FGD) systems on boilers firing low-sulfur western coal, it appears that a medium-efficiency ESP followed by an FGD scrubber may turn out to be the most cost-effective particulate control strategy for many applications.

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In the following sections we discuss the status of the cost and performance modeling efforts performed by Teknekron to date. The project is scheduled for completion within a year, and a presentation of the results is planned for the 1979 symposium.

COST MODELING

The various cost models that have been developed elsewhere were judged unsuitable for this study. Teknekron's evaluation of the available literature[1,2,3,4] revealed that these models lack the required detail and, while in general agreement with each other, do exhibit some differences. (Figures 1 and 2 summarize the projections of a few of the available capital cost models for cold-side ESPs and fabric filters, respectively.) Accordingly, Teknekron is developing capital and operating cost models for the various particulate control devices.

Particulate control costs reported in 1976 on FPC Form 67 by various utilities were evaluated to determine if the Form 67 data could be used as a source of cost information. Figure 3 illustrates the reported equipment and installation costs for 52 hot-side and cold-side ESPs as a function of collector area. Reported costs were corrected to mid-1976 by inflating pre-1976 costs by the Marshall and Swift Equipment Cost Index[5] while deflating post-1976 cost estimates by 7 percent per year. A comparison of Figures 1 and 3 reveals that the costs reported on FPC Form 67 are generally higher — in some cases 5 times higher — than those predicted by the various capital cost models.

In light of the uncertainties involved in using reported costs and existing cost models, Teknekron will develop independent capital and operating cost estimates for the various particulate control devices. It is on the basis of these estimates that the cost models will be prepared.

PERFORMANCE MODELING

Existing performance models are being adopted for this study. The ESP and wet scrubber performance models developed by Sparks[6] for use with a programmable calculator are being modified and expanded for use with a digital computer. Fabric filter performance modeling will be accomplished with GCA's simplified fabric filter model, reported elsewhere in the symposium proceedings. The Southern Research Institute's ESP performance model[7] is being used to calculate values for migration velocity as a function of particle size for various ESP current densities. These values will be used to update those reported by Sparks.

ESP vendor performance models are not available for use in this project. However, a review of the particulate control design parameters reported by utilities on FPC Form 67 revealed general trends among the various vendors in cold-side ESP specific collector area (SCA) versus design efficiency as a function

Figure 1. Cold-side ESP costs as a function of collector area.

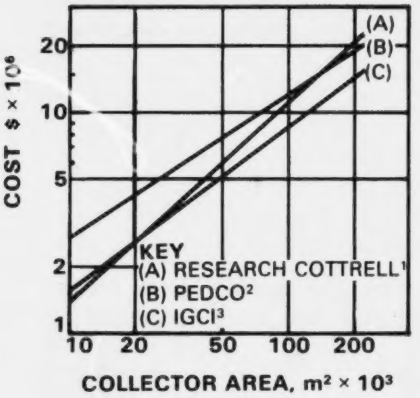


Figure 2. Fabric filter costs as a function of collector area.

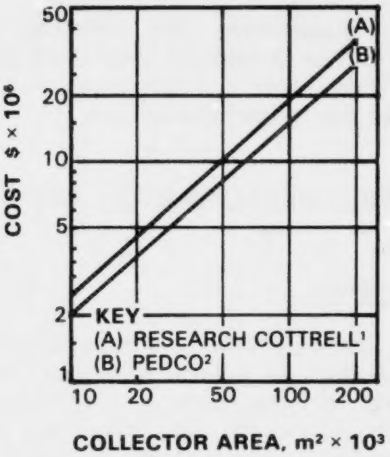


Figure 3. ESP costs reported to FPC in 1976.

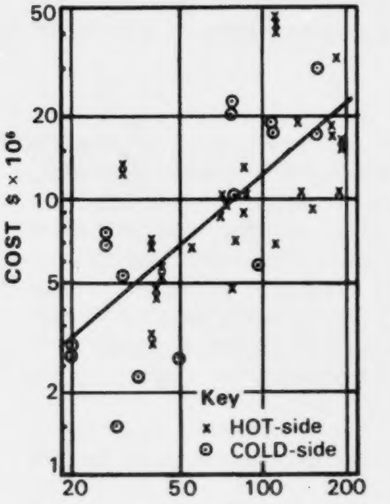
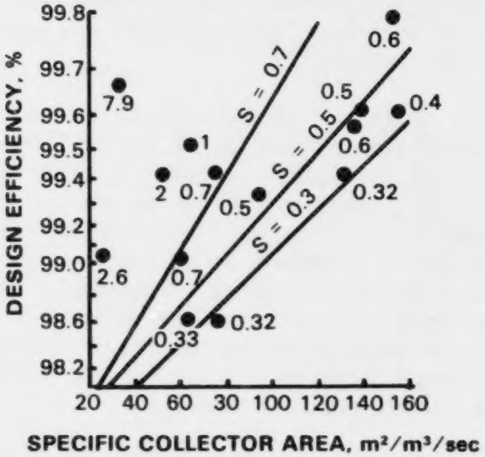


Figure 4. Design parameters for cold-side ESP as reported to FPC.



Coal sulfur content
is indicated next to the data point.

of coal sulfur content. These general trends, as presented in Figure 4, appear similar in shape to design correlations developed by Ramsell and reported by Oglesby and Nichols.[8] Specific collector areas as a function of design efficiency for hot-side ESPs reported on FPC Form 67 were clustered in that area of Figure 4 occupied by the coals with sulfur contents of 1 and 2 percent.

To supplement the existing performance models mentioned above, Teknekron has developed simplified performance models for wet scrubbers and ESPs. These models, which may be used in a portion of the study, are described briefly in the following sections.

SIMPLIFIED PERFORMANCE MODELS

Wet Scrubber

A computationally simple yet effective wet scrubber performance model that considers the effect of inlet particle size distribution has been developed by Teknekron on the basis of Calvert's cut diameter concept.[9] Using Calvert's approach, Teknekron calculated required cut diameters for various combinations of geometric mean particle diameter, geometric standard deviation of particle diameter, and overall penetration. Calvert's curves for B = 2 in the expression

$$\overline{P_t} = \exp(-A d_{pa}^{B}), \qquad (1)$$

where $\overline{P_t}$ = overall penetration, A is a dimensionless empirical constant, and d_{pa} = aerodynamic particle diameter, were used in this correlation. A value of B = 2 is appropriate for packed bed scrubbers, plate-type scrubbers, and gas atomizing scrubbers over a large portion of their operating range. The relationship between cut diameter and gas-phase pressure drop for gas atomized spray scrubbers (e.g., venturis) was used to calculate pressure drop as a function of cut diameter.

Figures 5 and 6 present typical relationships between pressure drop and overall penetration for varous particle size distributions. In Figure 5, where the picture is typical of particle size distributions having the same geometric standard deviation, the lines are parallel. In Figure 6, typical of particle size distributions having the same geometric mean particle size and different geometric standard deviations, the lines are convergent. Further investigation revealed the relationship presented in Figure 7 for the intercept of curves similar to those in Figure 6 and the geometric mean particle diameter. Likewise, a plot of the slope of the curves of penetration versus pressure drop similar to those in Figure 5 revealed the relationship shown in Figure 8 between the slope and the geometric standard deviation.

These relationships and ranges of validity can be summarized by the following formulae and limits:

$$\Delta P = a\,\overline{P_t}^{\,b} \qquad (2)$$

Figure 5. Overall particulate penetration versus pressure drop for a Venturi Scrubber.

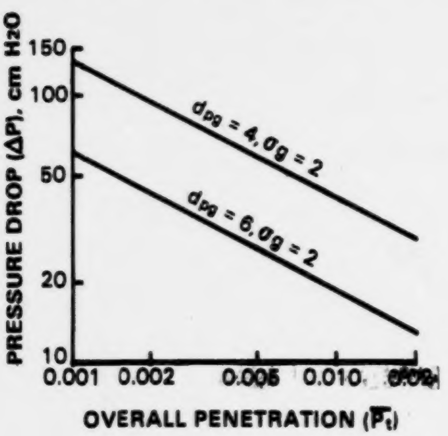


Figure 6. Overall particulate penetration versus pressure drop for a Venturi Scrubber.

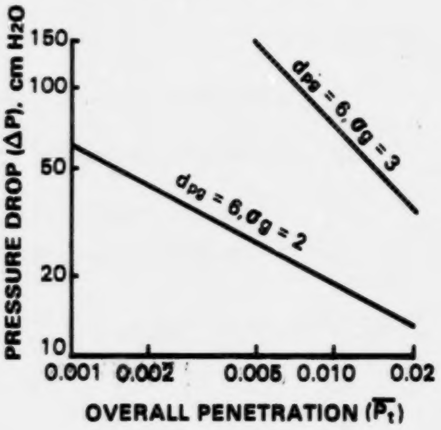


Figure 7. Intercept of the overall particulate penetration versus pressure drop curve for a Venturi Scrubber as a function of d_{pg}

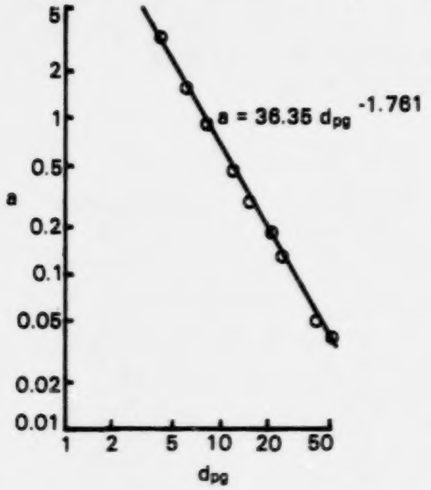
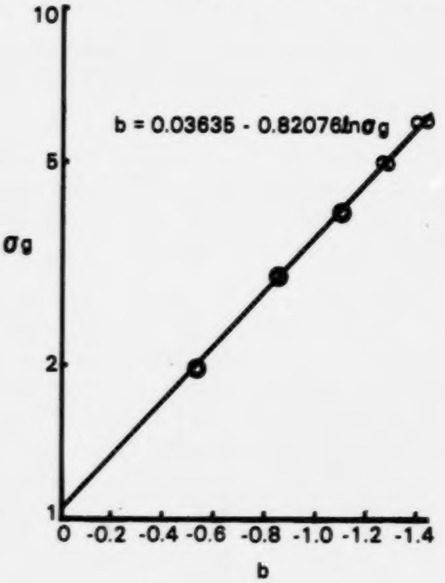


Figure 8. Slope of the overall particulate penetration versus pressure drop curve for a Venturi Scrubber as a function of σg



$$a = 36.35\, d_{pg}^{-1.761}$$

$$b = 0.03635 - 0.82076\, \ell n\, \sigma_g$$

Where:

d_{pg} = Particle geometric mean diameter (μ)

σg = Particle geometric standard deviation

$\overline{P_t}$ = Overall penetration

ΔP = Gas phase pressure drop (cm H_2O)

Valid range of variables:

$50 \geq d_{pg} \geq 4$

$6 \geq \sigma_g \geq 2$

$0.02 \geq \overline{P_t} \geq 0.001$

$150 \geq P \geq 10$

$\sigma g \approx 1.484\, d_{pg}^{0.409}$, which is typical of most utility boilers

In Table I scrubber pressure drops predicted by equation (2) are compared with those predicted by the use of Calvert's curves for various particle size distributions and penetrations. The two predictions agree very well.

Table I. COMPARISON OF PRESSURE DROPS PREDICTED BY CALVERT'S CURVES AND EQUATION (2)

d_{pg} (μ)	σg	$\overline{P_t}$	P (Calvert) (cm H_2O)	P (Equation 2) (cm H_2O)	Difference (%)
6	3	0.02	44.2	45.8	+3.4
		0.01	83.3	83.3	0
		0.005	144.4	151.8	+5.1
12	4	0.02	33.4	34.0	+1.8
		0.01	72.2	73.0	+1.1
		0.005	154.1	156.5	+1.6
20	5	0.02	28.3	28.3	+0.2
		0.01	70.8	69.0	-2.6
		0.005	132.0	132.9	+0.7
30	6	0.02	24.9	24.9	0
		0.01	72.2	67.3	-6.8
		0.005	144.5	140.0	-3.1

Electrostatic Precipitator

The general equation on which most ESP design correlations are based is the Deutsch equation,

$$\eta_t = 1 - \exp\left(-w \frac{A}{V}\right), \tag{3}$$

where η_t is collection efficiency for a given particle size, w is the migration velocity for that particle size, A is the collector area, and V is the volumetric flow rate. The Deutsch equation is often incorrectly applied to an aggregate of particle sizes; in that case, w is the precipitation rate parameter and η_t is the total collection efficiency. The precipitation rate parameter varies as a function of efficiency, which means that the selection of w must be application specific. Such an ad hoc approach is certainly undesirable for ESP design and scale-up. In this section we present simplified correlations which, like the Deutsch equation, are easy to use, but which are accurate for extrapolating to the higher efficiencies required by more stringent emission standards.

The Southern Research Institute has developed what is probably the most rigorous and detailed model of ESP behavior.[7] However, this model requires several empirically fitted parameters to handle the nonideal situations of rapping reentrainment, gas sneakage, and gas flow maldistribution, and it cannot be exercised without detailed information on the electrical properties of the ash and the internal geometry of the ESP. Overall efficiency is computed by numerical integration of penetration over the inlet particle size distribution. Still, in spite of the inherent difficulties in its use, the Southern Research model appears to be the best one available in terms of the physics of an ESP.

While the overall Deutsch equation represents the simplest approach for correlating ESP behavior, its use for predicting efficiency as a function of collector area is misleading and incorrect. Prediction of collection efficiency using the overall Deutsch equation is much too optimistic. Once the 99 percent efficiency level is reached, virtually all the particles leaving the ESP have diameters of less than 5 μm. Marginal improvements in efficiency are achieved by collecting more and more of these fine particulates, which can be done only by effecting relatively large increases in SCA. While a plot of efficiency versus SCA for the overall Deutsch equation yields a straight line on a semi-log plot, field data suggest a "tailing off" of the efficiency curve, giving lower than expected efficiencies. The w_k model, which is a modification of the Deutsch equation, is one way to simulate this behavior (see White[10]). Field data reported by Tassicker and Sproull[11] are fitted by this model quite well. However, the model still is empirical in that w_k must be estimated from performance data. Another way to simulate this behavior is to integrate the Deutsch equation over the size distribution as is done in the Southern Research Institute model.

The analysis of field data for collection efficiency as a function of diameters has shown that migration velocity can be modeled by the linear equation

$$w(x) = w_0 + W_1 x, \tag{4}$$

where x is the particle diameter. This is a departure from field charging theory, which predicts $w_0 = 0$. However, because of thermal charging and other phenomena, $w_0 \neq 0$, and this must be considered in the analysis of ESP performance. The parameters w_0 and W_1 characterize the coal used and are calculated from the resistivity (Sparks).[6] The straight line fits the data well for $x > 1.0$ micrometers.

The general expression for overall collection efficiency (η_t) using a linear migration velocity function can be written as

$$\eta_t = 1 - \int_0^{\infty} \exp \left[-A/V \, (w_0 + w_1 x)\right] \cdot P(x) \, dx, \tag{5}$$

where P(x) is the size frequency distribution of the inlet particulates.

In this work we have found that, for the particular case where P(x) is an exponential distribution,

$$P(x) = B \exp(-Bx), \tag{6}$$

the equation for collection efficiency can be integrated analytically. B in the above equation is related to the mean particle size. Edgar, Cukor, and Smith[12] have discussed the applicability of this equation to representative fly ash inlet distributions for three boilers: stoker, pulverized coal, and cyclone. The use of the single-parameter distributions gives excellent agreement with particulate loading data; indeed, the agreement is nearly as good as that accruing from the use of the two-parameter log-normal distribution.

The B's calculated for the three representative boiler fly ash curves are as follows:

Boiler Type	B
pulverized coal	0.040
stoker	0.017
cyclone	0.10

Note that, as B becomes larger, the particulates become finer.

If the linear form of w(x) is substituted into equation (5) and integrated using an exponential particle size distribution, the following correlating expression is obtained for total collection efficiency:

$$1 - \eta_t = \frac{B \exp\left(-\frac{A}{V} w_0\right)}{B + w_1 \frac{A}{V}} . \tag{7}$$

Using field data, Edgar and his colleagues evaluated the accuracy of the model by comparing results of the analytical integration procedure with those of a numerical integration. The analytical integration typically produced results that were within 0.1 percent of those obtained from numerical integration, even for overall collection efficiencies of more than 99.5 percent. Whether the analytical method is conservative or optimistic can be controlled by the fitting method. Lower predicted efficiencies for large particle sizes will give a conservative result.

A further test of the model structure was made using performance data from Tassicker and Sproull[11] as shown in Figure 9. The data in this figure are for ash from a low-sulfur Australian coal. In order to apply the proposed model, it is necessary to fit two parameters, namely w_0 and w_1. This can be done by numerically fitting two data points from the curve. The resulting function is

$$1 - \eta_t = \frac{B \exp^{-0.0022\ A/V}}{B + 0.0016\ A/V} , \qquad (8)$$

where A/V is expressed in ft^2/1000 ACFM. The metric equivalent would be

$$1 - \eta_t = \frac{B \exp^{-0.011\ A/V}}{B + 0.008\ A/V} , \qquad (9)$$

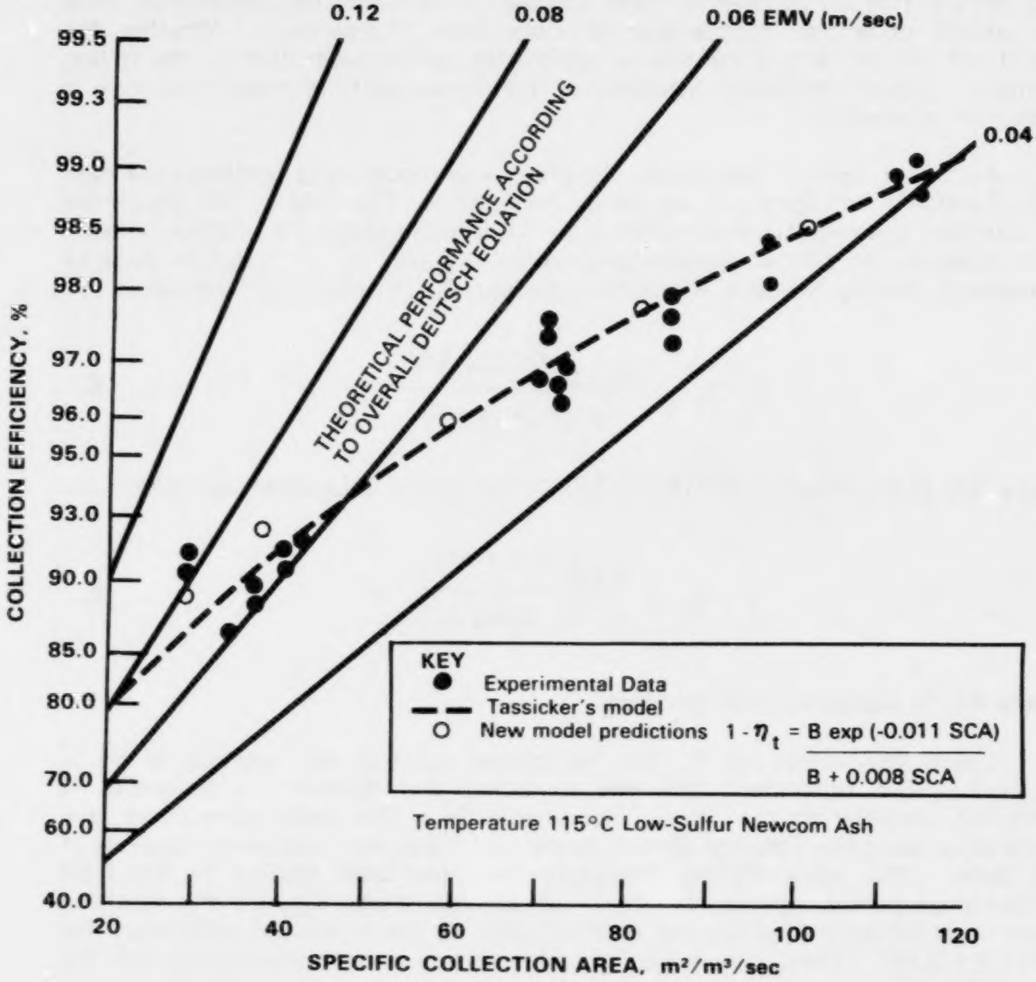
where A/V is expressed in m^2/m^3/sec.

Calculated values of η_t for the above equation are marked as o's in Figure 9. The agreement between predicted and measured efficiencies is excellent, considering the limited data available. The dashed-line curve is a correlation using the Tassiker-Sproull model and based on a regression analysis of the data. This same fitting procedure has also been applied to the field performance curves reported by Kiff[13] of Joy Manufacturing, and the resulting equation predicts the efficiency within 0.001 of the measured efficiency for $0.98 \leq \eta \leq 0.997$. These preliminary results are extremely encouraging; with the availability of further data, it is believed, the general approach will be successful for a wide range of coals.

Analytical expressions for collection efficiency can be derived for devices in series, as discussed by Vatavuk.[14] Vatavuk's expressions have been slightly modified here to treat a penetration of less than 1.0 for x = 0 (Vatavuk's expressions assume 1.0 in all cases). If $Q_1 = 1 - c_1 e^{-\gamma_1 x}$ and $Q_2 = 1 - c_2 e^{-\gamma_2 x}$ represent the efficiency curves for the first and second devices in the series, then the expression for total collection efficiency becomes

$$\eta_t = \int_0^\infty [Q_1 + Q_2 (1 - Q_1)] \quad Be^{-Bx}\, dx. \qquad (10)$$

Figure 9. Collection efficiency as a function of SCA, illustrating the fit of the regression equation to some experimental data from Tassicker and Sproull (II).



Upon integrating, the analytical expression for total efficiency is

$$\eta_t = 1 - \frac{Bc_1c_2}{B+ \gamma_1 + \gamma_2} \qquad (11)$$

The interesting ramification of the above equation is that, according to the fitted curves, control devices are commutative. Thus, in the above equation, c_1c_2 and $\gamma_1 + \gamma_2$ are commutative. While this may not be strictly true in practice — for example, the behavior of an ESP does depend somewhat on the total ash loading — it is probably true as an approximation. Equation (11) does provide an extremely quick method of calculating overall efficiencies for several devices. This type of model could also be used to model the combined collection efficiency of an ESP followed by a scrubber.

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ELECTROSTATIC PRECIPITATION IN JAPANESE STEEL INDUSTRIES

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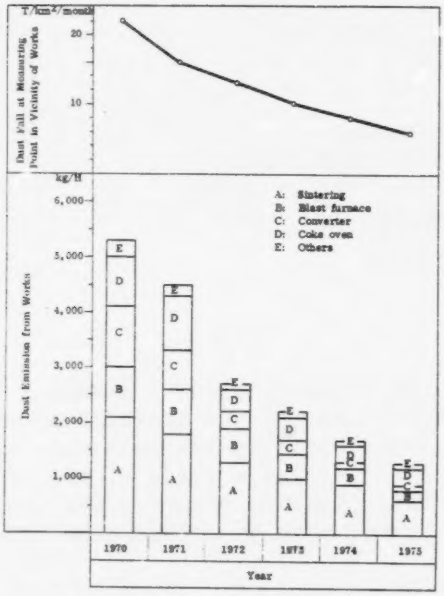
ABSTRACT

Control of particulate pollutants in Japanese steel industries has rapidly improved since 1970 when the environmental and emission standards were established by government. Here, electrostatic precipitators are playing a major role in the particulate control of large scale plants, and their application range is increasing. In this paper is reported the present status of electrostatic precipitators there, with an emphasis on those used in sinter and blast furnaces.

INTRODUCTION

Tremendous efforts have been made for pollution control in Japanese steel industries since 1970 when the environmental and emission standards were established by government. The environmental standard for particulate is 100 $\mu g/m^3$ for 24 hours, and 200 $\mu g/m^3$ for 1 hour, and the emission standards varies from 0.4 to 0.05 g/Nm^3 according to the kind and size of processes and also to the territory. However, the target of emission level has been laid on 0.05 g/m^3 which corresponds to the most stringent value in the standard and almost invisible level. The Japanese steel industries have more than achieved this goal, and are maintaining now really comfortable environment both inside and outside of thier works, as shown in Fig. 1. Fig. 2 represents the chronological decrease in dust emission from various plants and dust fall in the vicinity of works producing 7 - 8.5 million tons of steel annually. Statistically, the investment for pollution control amounted on average to about 20 % of the total plant cost, where that for particulate control occupied about 40 %. The occupation of place by the pollution control equipments reaches almost the same in total as that for production equipments in the most modern steel works.

Figure 1: See following page



Note: This chart shows the case of typical steel plants which produces 7 to 8.5 million tons of steel annually.

Fig. 2 Chronological decrease in dust emission and dust fall (Nippon Steel Corp.)

One of the most remarkable features in these control efforts is that they made themselves a large amount of studies and experiments by their own staffs to grasp each condition of dust emissions, and to find best planning as well as technical solutions for particulate control. This resulted in the development of their own novel electrostatic precipitators.

Electrostatic precipitators are playing a major role in particulate control in the large essential processes, including ore sintering machine (exhaust system, ore feeding system, sinter crushing feeder, cooling system), blast furnace (gas cleaning system, casting house), basic oxygen furnace (converter mouth), coke oven (dry main), electric furnace (furnace top), rolling mill (hot scarfing machine) etc.

In this paper is reported the present status of electrostatic precipitators in Japanese steel industries, with a special emphasis on those used in the sinter machine and blast furnace).

ORE SINTER MACHINE

Most of iron ore is imported from Australia and other countries in powdery form which is sintered to be fed to the blast furnace. Most of the sinter machine is of Dwight Lloyd type where ore is fed with powdery cokes and other materials to the upstream end of the moving grate at which cokes are ignited. Combustion gas is exhausted downwards through a number of wind boxes and lead to the "sinter main precipitators", as shown in Fig. 3. The precipitators are also used for control of dust emissions from the ore feeding system, sinter crushing feeder, sinter cooler etc. These are called "environment precipitators".

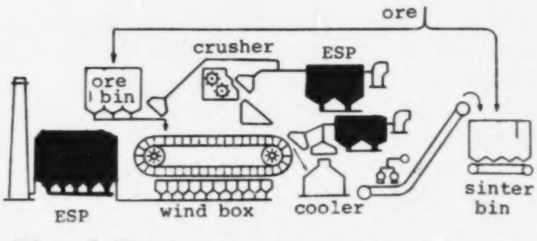


Fig. 3 Electrostatic precipitators in sinter machine system

Sinter Main Precipitator

The sinter main gas has the lagest gas volume (7,500 - 54,000 m^3/min) among all the processes, and contains very fine dust primarily out of Fe_2O_3. The temperature of gas varies widely from 80 to 250 °C according to the prevailing operating conditions. The particle size ranges widely from 0.1 to 100 microns, 5 % of which lies under 5 microns. The dust resistivity in the operating condition is very high in the range of 10^{11} to 10^{13} ohm-cm. The gas also contains a high content of SO_2. Its dust collection has been made by electrostatic precipitators until now, because of low running cost and better maintainability compared to other means. However, the dust collection of sinter main gas has been the most difficult task even for electrostatic precipitators owing to the factors described above, and its complete solution has not yet been achieved although the satisfactory emission level of 0.05 g/Nm^3 has been reached by using large volume precipitators of either conventional or novel types (Fig. 4 and 5). It has been confirmed that a conventional type precipitator can collect the sinter main dust to the level of 0.08 - 0.05 g/Nm^3 when an improved rapping with sufficient intensity is used and the precipitator volume is increased. Fig. 5 shows a photograph of a novel type precipitator called "ESCS (Electrostatic Space Cleaner - Super) developed by Nippon Steel Corp. which has a very large electrode spacing and uses a high dc voltage of about 200 kV. There are two types of ESCS precipitators; one is "House Type" (Fig. 6) and the other is "Straight Type" (Fig. 7). Both types of ESCS precipitators, having a large volume, can collect the sinter main dust to the level of 0.05 g/Nm^3. Back discharge occurs in both the conventional and the novel type precipitators, which can be visually detected only in the dark at night, and this inevitally results in such a large precipitator volume. Back discharge is mostly of the glow-mode, but it sometimes turns into the weak streamer-mode at protuberant portions or members of electrodes. The thin dust layer to be resulted by an intense rapping is likely to hinder back discharge to

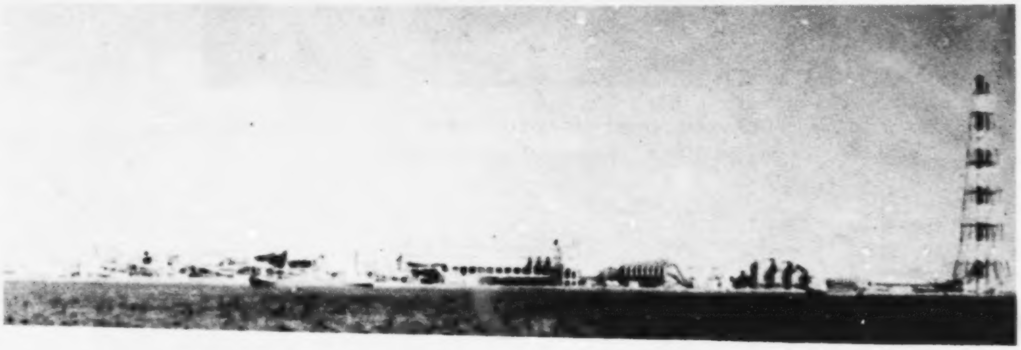


Fig. 1 Wakamatsu Sinter Plant (Nippon Steel Corp., 24,000 t/d)

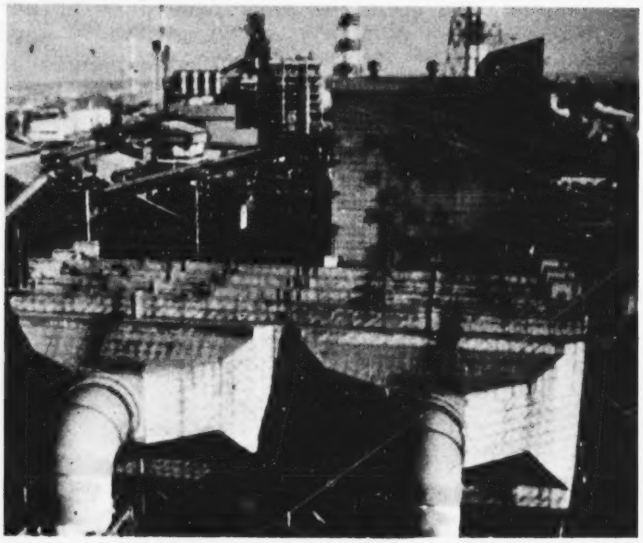


Fig. 4 Conventional precipitator for sinter main gas (Mitsubishi Heavy Industries)

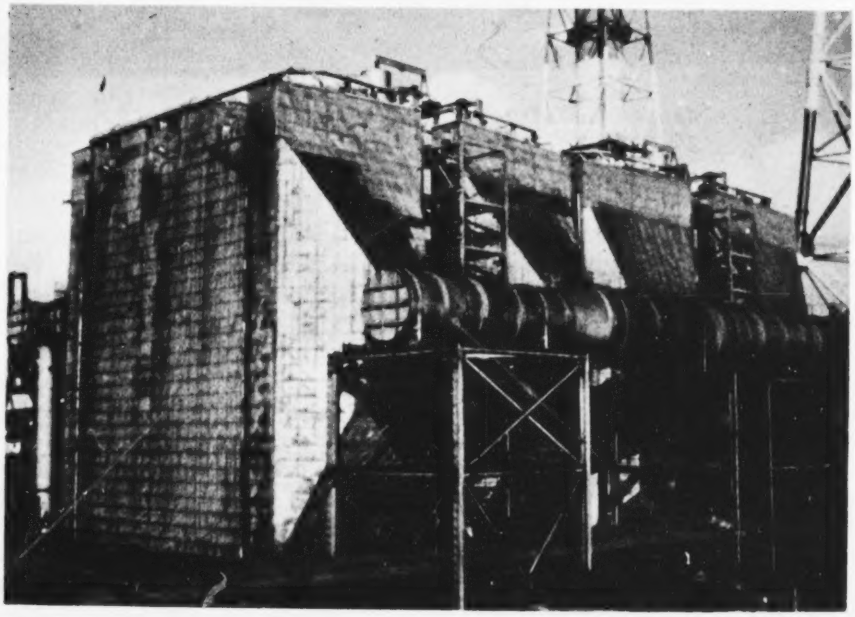


Fig. 5 ESCS (Electrostatic Space Cleaner) type precipitator (Nippon Steel Corp.)

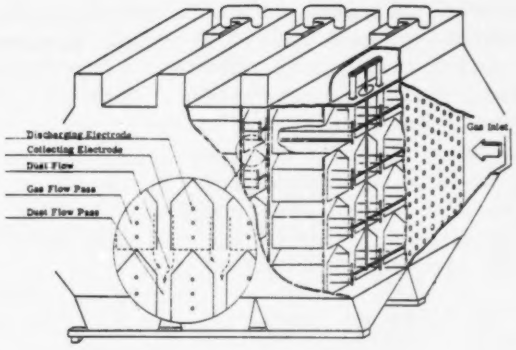

Discharging Electrode
Collecting Electrode
Dust Flow
Gas Flow Pass
Dust Flow Pass
Gas Inlet

Fig. 6 House Type ESCS precipitator

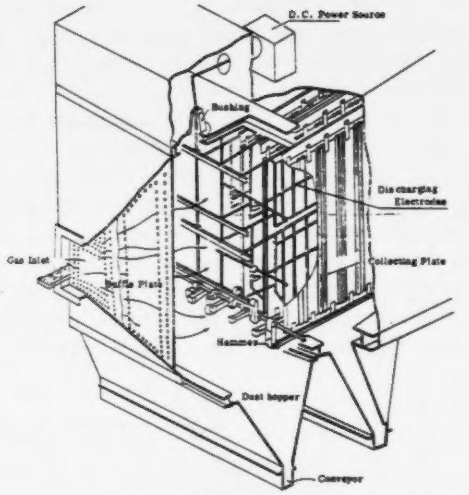

D.C. Power Source
Bushing
Discharging Electrodes
Gas Inlet
Baffle Plate
Collecting Plate
Hammer
Dust hopper
Conveyor

Fig. 7 Straight Type ESCS precipitator

turn into the detrimental streamer-mode[1]. The field strength in the collecting zone has to be kept low, also to meet this purpose[2]. The sinter main dust normally contains alkaline metals in amounts up to 5 to 10 %, and it has been confirmed that dust emission rises proportinally with the increase in the alkaline metal content. This is considered to be the result of streamer enhancing effect of alkaline metal components[1].

Control of gas temperature is one of the most important prerequisite conditions for the sinter main precipitators, since resistivity of the sinter main dust becomes maximum at gas temperatures of 100 to 150 °C, resulting in the increase in dust emission due to severe back discharge (Fig. 8). Lowering of gas temperature down to the dew point or less leads to corrosion of discharge and collecting electrodes, whereas raising t up to 250 °C or above results in thermal distorsion of collecting electrodes. Temperature and volume of gas in the wind boxes distribute as illustrated in Fig. 9, so that control of gas temperature at the precipitator

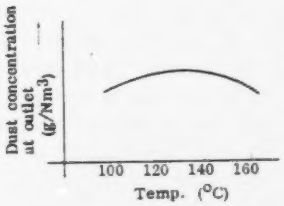


Fig. 8 Dust emission vs. temperature.

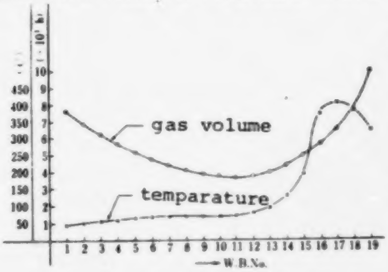


Fig. 9 Gas volume and temperure at each wind box.

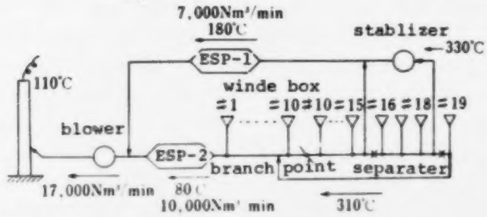

7,000Nm³/min
180°C
stablizer
330°C
ESP-1
110°C
winde box
≠1
≠10
≠10
≠15
≠16
≠18
≠19
blower
ESP-2
branch
point
separater
17,000Nm³/min
80°C
10,000Nm³/min
310°C

Fig. 10 Temperature control by gas separation in wind boxes.

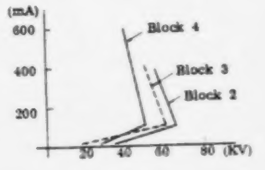


Fig. 11 V-I characteristics when electrode deformation occured.

inlet can be made by suitable separation and combination of gas out of the wind boxes as indicated by Fig. 10, where a gas stabilizer by water spray is installed at the branch of highest temperature (330 °C) to lower it down to a suitable level. Fig. 11 represents voltage-current charactersitics to be observed when electrode deformation occured due to abnormal temperature rise. Another serious trouble which occured at abnormal temperature rise up to 250 to 300 °C is the sudden burning of combustible dust on collecting electrodes which originated from grease-rich mill scales used as raw materials for sinter. The collecting plates burnt partially to cause a large deformation. To avoid such troubles, controlling of the oil and grease content of raw gas below the safety level, continuous monitoring of gas temperature, emergency rapping system, and introducing of cold air if gas temperature exceeds a preset level have now been adopted.

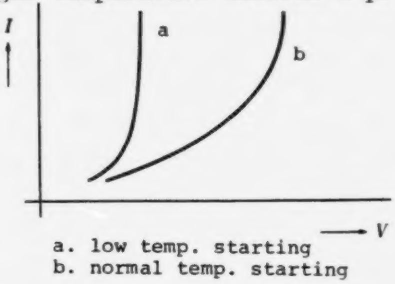


Fig. 12 V-I characteristics and starting temperature.

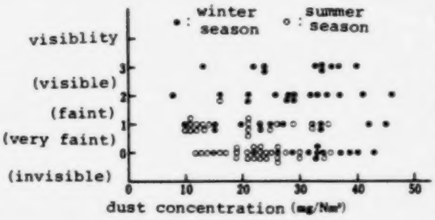


Fig. 13 Emission concentration vs. visibility

Abnormal dust deposition due to improper rapping operation also results in lowering of the collection performance. It is considered as highly desirable to be able to control the time schedule and intensity of electrode rapping. Here, an emphasis should be laid on the dust deposition control at the start and stop of the sinter machine. In view of the severe regulation of dust emission, it is compelled to operate the precipitators at the start of sinter machine when gas temperature is lower than dew point. This, however, results in a severe deposition of adhesive dust layer which later cause a severe back discharge, as shown in Fig. 12. In order to solve this problem, a trial was made at a sinter main precipitator with 40,000 m^3/min gas volume to warm up the electrodes before the start by flowing a hot air at 100 to 130 °C. It can be said that the key to mastery of the dust control is not only a reasonable design of precipitator itsel but also a good system planning and maitance of the whole process.

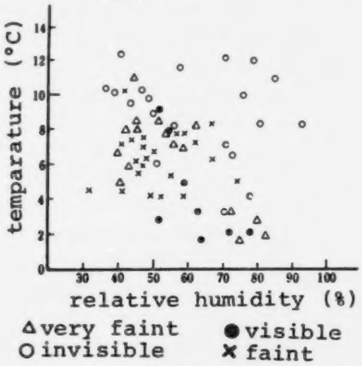


Fig. 14 Effects of temperature and humidity of atmospheric air on visibility of stack gas.

Fig. 13 shows the effect of emission concentration from the sinter main stack on its stack gas visibility measured in winter and summer times. It can be seen that, in the low concentration range below 0.05 g/Nm^3, no correlation can be found between the concentration and visibility, whereas a marked difference exists between winter and summer times[3]. Fig. 14 represents the effects of temperature and humidity of atmospheric air on the

the visibility measured in winter time. The visibility becomes maximum when relative humidity of air exceeds 50 % and its temperature is lower than 5 °C. The visibility becomes zero when air temperature rises above 10 °C. The color of the sinter main stack gas is either reddish or white in the frequency ratio of 2 : 1. The redish color appears in the fine weather when air temperature is above 10 °C (with the frequency of 90%). No correlation could be found between the visibility and solar energy (cal/cm^2) or other meteorological factors.

Environment Precipitator

Dusts comming into the environment precipitator systems are of larger size compared to that in the sinter main system. Their resistivity is also lower than that of the sinter main dust, although it can become as high as 10^{12} - 10^{13} ohm-cm in case of some sinter cooler dusts. The sinter cooler dust contains primarily Fe_3O_4 and also small amount of Fe_2O_3. The most remarkable feature of this dust is the large dependence of its resistivity on electric field. It lowers not rarely as much as one order of magnitude or more when the applied field increases from several hundreds to several thousands V/cm. Among the environment dusts, that from the sinter cooler has been considered as comparatively difficult to collect. However, this can be collected by a conventional type precipitator, more or less satisfactorily. A novel type precipitator using the bias-controlled pulse charging system in combination to a zig-zag shaped after collecting zone out of channel electrodes, which is named "PAC-ES Type Precipitator"[4], has been in successful use since March 1978 in a sinter cooler system with 11,000 m^3/min gas volume (Fig. 16).

Figure 15: See following page

BLAST FURNACE

Either venturi-scrubbers or conventional wet type electrostatic precipitators are used to clean the gas from the top of blast furnce, which then is led to a gas holder. No explanation will be needed for this type of precipitators. A modern use of precipitator in this field is the "Roof-Mounted Type Precipitator" which is installed on the roof of a casting house to control abnormal dust emission out of tap holes at the beggining and end of casting operation (Fig. 16)[5]. The precipitator is of vertical flow type using natural convection for gas draft, and equipped with collecting electrodes out of conducting plastic plate, light in weight and free of corosion, over which water irrigation is performed intermittently. Control of normal dust emission is made by a conventional practice which combines hoods with bag filters or electrostatic precipitators. Large merits of the roof-mounted type precipitator lie in its simple construction, very low

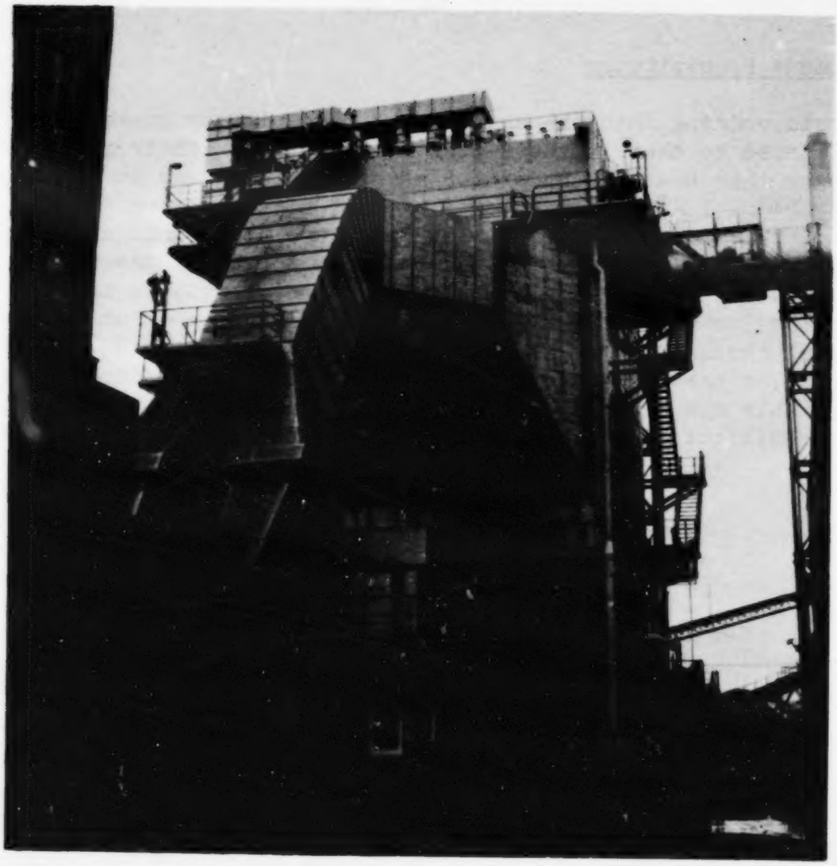


Fig. 15 PAC-ES Type precipitator for sinter cooler dust (IHI Heavy Industries Co.)

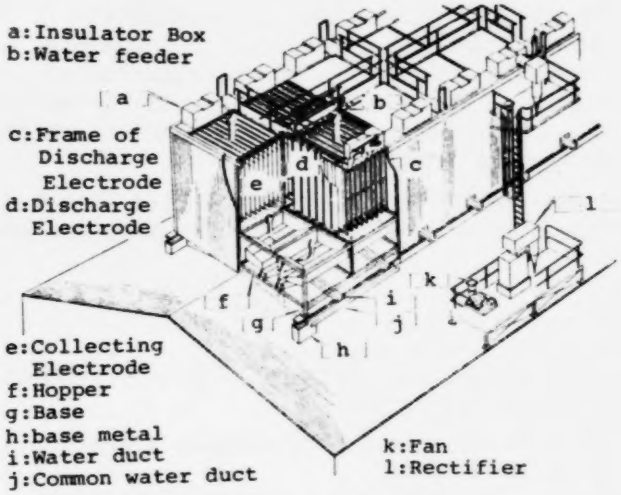


Fig. 16 Roof-Mounted Type precipitator
(Sumitomo Heavy Industries Ltd.)

running cost, lack of noise source, use of roof area for installation space, and a very good collection performance. Dust is primarily out of Fe$_2$O$_3$ and Fe$_3$O$_4$ (1 : 1), and can easily removed by water spray. Its maximum concentration amounts to 0.6 g/Nm3 which is reduced down to about 0.03 g/Nm^3 at the precipitator outlet. Its resistivity ranges from 10^{11} to 10^{12} ohm-cm in temperature range of 30 to 90 °C, and its particle size is almost the same as that in converter dust. The sizing factor takes minimum at a gas velocity of 1.0 to 1.2 m/s, at which collection performance rises with current density up to 20 mA/m^2. A large scale roof-mouted type precipitator with 30,000 m^3/min gas volume at 60 °C, installed at No. 3 Blast Furnace in Kakogawa Works, Kobe Steel Corp., has been in very successful operation as described above. Its design parameters are: gas velocity = o.92 m/s at 60 °C, gas temperature = 40 - 90 °C, total duct area = 21,2 m width x 20 m length x two sets, inlet dust concentration = 0.6 g/Nm^3 dry, outlet dust concentration = 0.03 g/Nm^3 dry, power consumption for high voltage source = 245 kW (420 kVA), power consumption for motors = 22.5 kW (30 kVA), water consumption = 1.2 m^3/min (recycled). An economic assessment made by Sumitomo Heavy Industries Co. revealed that the total running cost of this precipitator amounts to 24.5 million Yen/year whereas that in a bag house with equal gas capacity 187 Yen/year, leading to the cost reduction of 120 million Yen/year in the side of the precipitator.

OTHER PROCESSES

Conventional precipitators are in use for dust collection of gases from converter mouth, electric furnace, hot scarfing machine etc. The roof-mounted type precipitators have been installed also for control of dust emissions from LD-converters, basic oxygen furnaces, and electric furnaces. Wide-spacing type precipitators having electrode spacing of 20 to 30 cm are in very successful use in electric furnaces. A novel type precipitator with water-cooled collecting electrodes has been developed recently, and proved to be efficient for high resistivity dusts.

CONCLUSION

The present status of electrostatic precipitators in Japanese steel industries is described briefly. The target of emission level at 0.05 g/Nm^3 has already been achieved now by means of a good system planning and by using conventional, improved or novel types of precipitators. It should, however, be added that back discharge occuring in the sinter main precipitators remains still unsolved, requiring the installation of too large and expensive precipitators. The development of entirely new precipitators, including the use of pulse energizing, are going on, so that they may substitute in future the old precipitators.

The author is very much indebted to Mr. A. Mukaida, Vice-Director of Environmental Control Division, Nippon Steel Corp. for his help and advice in preparation of this paper.

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INSTALLED COST PROJECTIONS OF AIR POLLUTION CONTROL EQUIPMENT IN THE U.S.

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Northbrook, Illinois 60062

BACKGROUND

About one year ago, The McIlvaine Company was asked by the Environmental Protection Agency to make cost projections for air pollution control equipment through 1982. This study was completed in October 1977, so the figures that we will discuss today were compiled nine months ago. This is a very rapidly changing industry. Unlike many other industries, both the technology and the legislation are changing at an incredible rate. For instance, at the time we made our projections we assumed that no fabric filters would be used in the absorption of SO_2 for utilities. A few months later it was announced that a 415 MW system would be installed by the Coyote Project, incorporating a spray dryer and fabric filter for SO_2 removal. At present the potential impact of this technology is still very much in question, but because of the very large potential in the utility industry even a small percentage use of fabric filters for this purpose would markedly change the installed cost projections for this equipment. For this reason we made a special attempt in our report to precisely define the assumptions we used in the preparation of our figures in order to allow those with different assumptions to use our data to derive possibly different figures of their own.

However, even though nine months have passed, we still believe our projections are fairly realistic and that, at least at this moment, our assumptions are valid.

Our complete report is available from EPA, and it has been included as a section in The McIlvaine Scrubber Manual, The Electrostatic

Precipitator Manual, and The Fabric Filter Manual, so we do not feel it would be beneficial to repeat the conclusions of this report in detail here. Instead, we would like to analyze various of our conclusions by illustrating the significant changes in estimated totals using different assumptions from those previously used. First of all, you might be interested in learning how we obtained our numbers.

Most air pollution market forecasts are based on projecting general available data. Exceptions to this are figures compiled by The Industrial Gas Cleaning Institute and the Department of Commerce, which are based on data obtained from individual manufacturers. However, both IGCI and Commerce statistics are based on a limited number of companies.

The McIlvaine Company, in pursuit of its publishing activities, has obtained large quantities of data on a continuing basis from nearly 100% of the manufacturers of air pollution control equipment. This data has been used extensively in the calculation of installed costs.

Some of the projections made in this forecast differ considerably from other projections. It is believed, however, that the large and unique data base has provided a higher potential for accuracy than could be obtained by other organizations. Much of the data was obtained from individual manufacturers on a confidential basis. Therefore, although figures for individual companies were obtained, only group totals are provided.

BASIC ASSUMPTIONS AND CLARIFICATION

All prices given for 1977 and future years are in 1977 dollars. Assuming inflation will continue, all figures are understated in terms of actual dollars by the amount of inflation between 1977 and the year for which the projections are made.

We have elected to furnish data related to the year in which orders were placed or, in other words, "bookings" as opposed to shipment year or year of operation. Generally, the cash flow from purchaser to manufacturer begins within six weeks subsequent to the formal order placement and continues for months subsequent to the installation of equipment. Purchasers often hold retainers of as much as 10% of the total contract until the equipment is adequately demonstrated, which would typically be six months subsequent to shipments of major components. Thus, actual cash flow figures are 6 to 18 months subsequent to booking figures. Booking figures have been used because they have specific identifiable dates, whereas shipment and startup dates are not readily identifiable.

Flange to flange equipment costs include the equipment (scrubber, fabric filter or precipitator) without auxiliaries or, in other words, the purchase price of the device from the inlet to outlet flange. For example, the cost would not include the main air moving fan but would include fans used with fabric filters for reverse air cleaning of the bags.

Installed cost includes equipment both primary and auxiliary, ductwork, foundations, engineering, startup service and electrical controls and liquid clarification in the case of scrubbers. It does not include other total investment costs such as interest on the investment during construction and preparation of the site.

TRENDS - INDUSTRIAL SECTOR

When examining the industrial sector, one has to separate industrial boilers from the general industrial air pollution control sector.

With a new emphasis on coal use, projections are that by 1985 over 33% of industrial energy will be supplied by coal-fired boilers as opposed to the 18% now being supplied. Our further assumption was that precipitators would be furnished for 25% of the requirement for industrial boiler particulate control, scrubbers for 35% of the requirement and fabric filters for 40% of the required capacity. These estimates reflect the recent trend away from precipitators, which have historically been used on this application.

Projections are that the nonboiler industrial segment will grow at a considerably slower rate. Fabric filters are projected to increase at an 11% rate, precipitators at a 10% rate and scrubbers at a 12% rate. Total yearly figures, therefore, reflect the combined increase of boiler and nonboiler expenditures. These figures differ from A.D. Little's 1975 projection of an 11% increase in particulate control equipment on a yearly basis from 1976 to 1985 and from Kidder Peabody's more conservative estimate of only 7%. However, our figures reflect some of the impact of the clean air amendments and energy conversions possibly not taken into account in these earlier studies.

Graph No. 1 shows our projections for control equipment expenditures in the industrial sector on an installed-cost basis through 1982. These figures include all equipment except that furnished to utilities and SO_x control systems for industrial boilers. It is interesting to note that when utilities are excluded from the figures, the fabric filter is the most popular air pollution control device in the other sectors, with scrubbers and precipitators receiving almost equal attention.

TRENDS - UTILITY SECTOR

For particulate control on new boilers the assumption is that 66,000 megawatts of high sulfur coal burning boilers will be ordered by

1982 for installation by 1985. The further assumption is that 67,000 megawatts of low sulfur coal burning boilers will also be ordered by 1982. These figures are in agreement with those contained in the Temple, Barker and Sloane study.

Fabric filters are more likely to be used with low sulfur coal because of the higher resistivity, which makes precipitation difficult. Also where flue gas desulfurization is required, the precipitator-absorber or scrubber-absorber combination is more likely to be used than a fabric-absorber combination. Therefore, we project that while fabric filter will capture 45% of the low sulfur installations, it will capture zero percent of the high sulfur installations. Precipitators will be used for 45% of the low sulfur installations and 85% of the high sulfur installations. Particulate scrubbers will be used for 10% of the low sulfur installations and 15% of the high sulfur installations.

In addition to new units, particulate control on 8000 megawatts yearly of existing capacity has been estimated to bring units into compliance with local regulations and will be used for normal replacement. Both high and low sulfur coal will be burned. In many cases the additional particulate control will be required because of the switch from high to low sulfur coal. Consequently, we project 20% of these retrofit installations will include fabric filters, 10% scrubbers and 70% precipitators.

Also of great significance is the trend toward using lower efficiency precipitators in systems where the precipitator precedes the flue gas desulfurization unit. In the system slated for Bruce Mansfield No. 3, there is a 95% efficient precipitator to be followed by an absorber which will remove SO_2 as well as capture 4+% of the dust. This reduces the precipitator size and cost by a very substantial amount.

Projections for utility particulate expenditures are shown on Graph No. 2. Precipitators are projected to capture the lions share of this market.

The most significant trend is the huge projected expenditure for scrubbers for utility SO_x removal. By 1982, the yearly expenditure of nearly $1.6 billion for SO_x utility scrubbers will represent 30% of all the air pollution control expenditures in that year.

Projected orders for new equipment are based on the assumption that 156,000 MW of FGD systems will be required by 1985 but that only 70% of the required systems will be ordered by 1982. This is based on the assumption that all new low sulfur coal-fired boilers will also require FGD systems since the passage of the new Clean Air Amendments.

The forecast assumes that orders for FGD systems will peak in 1982. Orders placed in that year will result in installations operating in 1985. Since noncompliance penalties are to be imposed, the assumption is that the bulk of the orders will be let in time to avoid such penalties.

Graph No. 3 shows the rapid rise in the use of scrubbers, specifically due to the increased use by the utility industry. Between 1974 and 1982 scrubbers will have undergone the Cinderella-like transformation from the least used of the air pollution control equipment types to the most used. In fact, as shown in Graph No. 4, scrubbers are being and will be purchased in quantities larger than precipitators and fabric filters combined.

TOTAL MARKET

Between 1976 and 1982 we predict a 300% increase in the total air pollution control equipment market - from $1.7 billion to over $5.2 billion in 1982. This rapid increase is depicted in Graph No. 5. As mentioned earlier, these figures are subject to rapid change based on technological and legislative factors. If, for instance, legislation is not enforced as rigidly as we anticipate it will be, polluters might delay installation of equipment, so that instead of ordering the large anticipated amount of equipment by 1982, the order peak might be pushed back to a much later date. However, nine months after our original estimate we do not see any such trend developing, nor do we see any particular technological change that would significantly change the individual totals among the three major equipment types. It should again be noted that while we talk in terms of total air pollution control equipment, we have not included in this study the cyclones, adsorbers and some of the other less frequently used equipment types but have instead included only fabric filters, precipitators and scrubbers.

EFFECTS OF TECHNOLOGY AND LEGISLATIVE CHANGES

It is interesting to speculate on the potential effects of technology and legislative changes. A good example is the present discussion in the utility industry relative to different methods of particulate control. Setting federal and state regulations to very low emission levels might force a much wider use of fabric filters. One EPA official was quoted as leaning toward mandating fabric filters universally for utility particulate control or, in other words, 100% use of fabric filters for utility particulate.

Graph No. 6 shows the effect on fabric filter sales through 1982 if this were immediately to take effect. It can quickly be seen that the huge utility potential would greatly increase fabric filter sales. On the other hand, we can speculate what would happen if utilities found that bag life was much lower than had been anticipated. For instance, if the new fabric filters being installed experience bag life of less than one year, utility baghouse sales might drop to zero. Graph No. 6

also shows the effect of this technological development.

Whereas fabric filter sales will be very much affected by the utility decisions, the same is not true for particulate scrubbers.

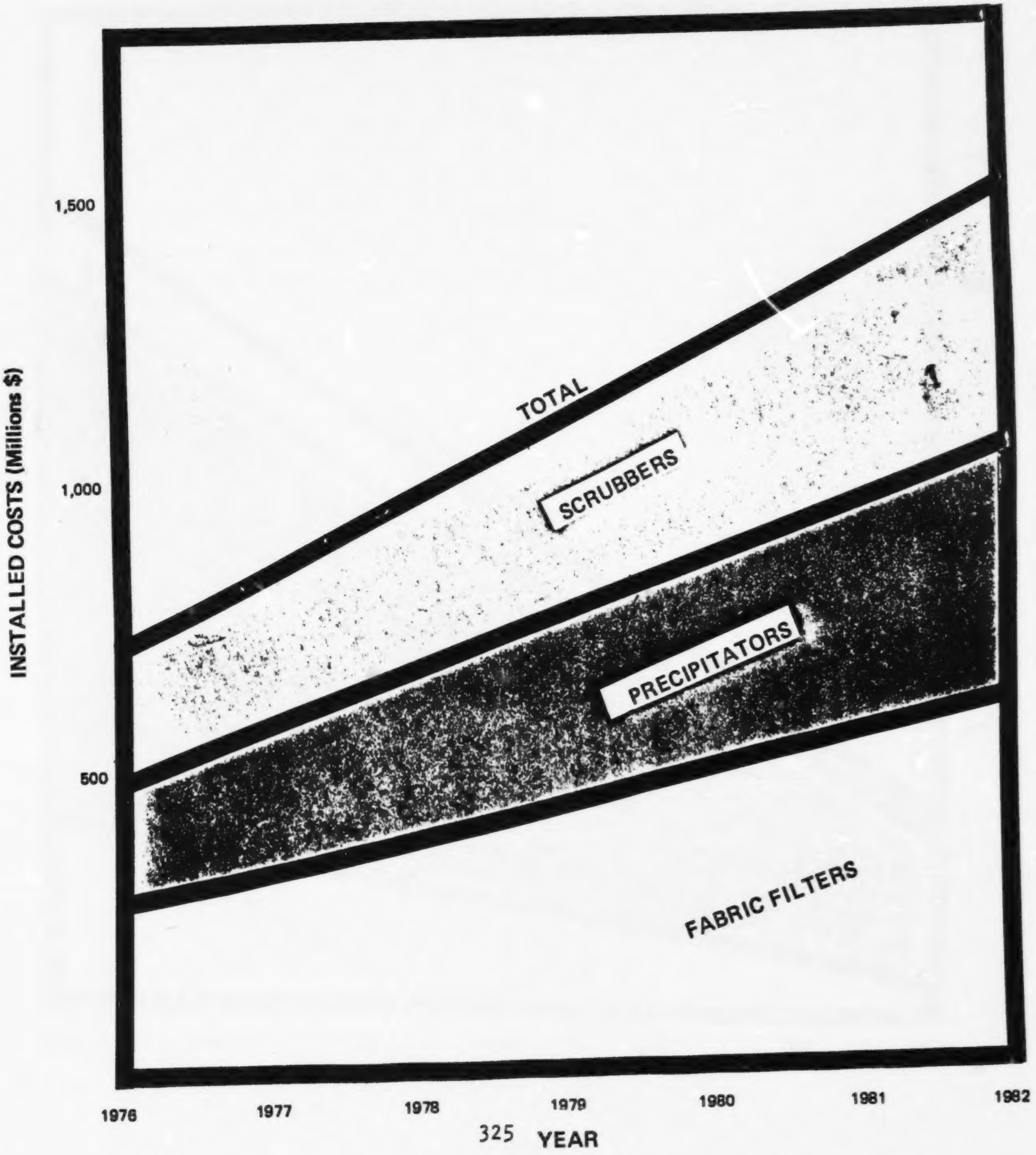
Graph No. 7 shows the effect on total scrubber sales assuming both zero percent and 100% usage of scrubbers for utility particulate removal. Zero percent would result if either precipitators or fabric filters were improved technically to the point of considerable superiority to scrubbers. Although the converse is not likely, if technological development in scrubbers were to allow high removal at low energy consumption, scrubbers could capture a much higher percentage of the utility market. The logic in this is based on the ability of the scrubber to remove both the particulate and SO_2 in one device.

Graph No. 8 shows the extreme sensitivity of the precipitator market to utility particulate sales. Should legislation or other factors preclude precipitators from the utility industry, over two-thirds of the precipitator market would disappear. Although not likely, this is a remote possibility if particulate emission levels were to be set at levels impossible to achieve with precipitators. Conversely, new developments with precipitators, such as high intensity ionizers, might make precipitators even more competitive. If they were to obtain 100% of the particulate market, a sharp increase in sales would be experienced, as shown in Graph No. 8.

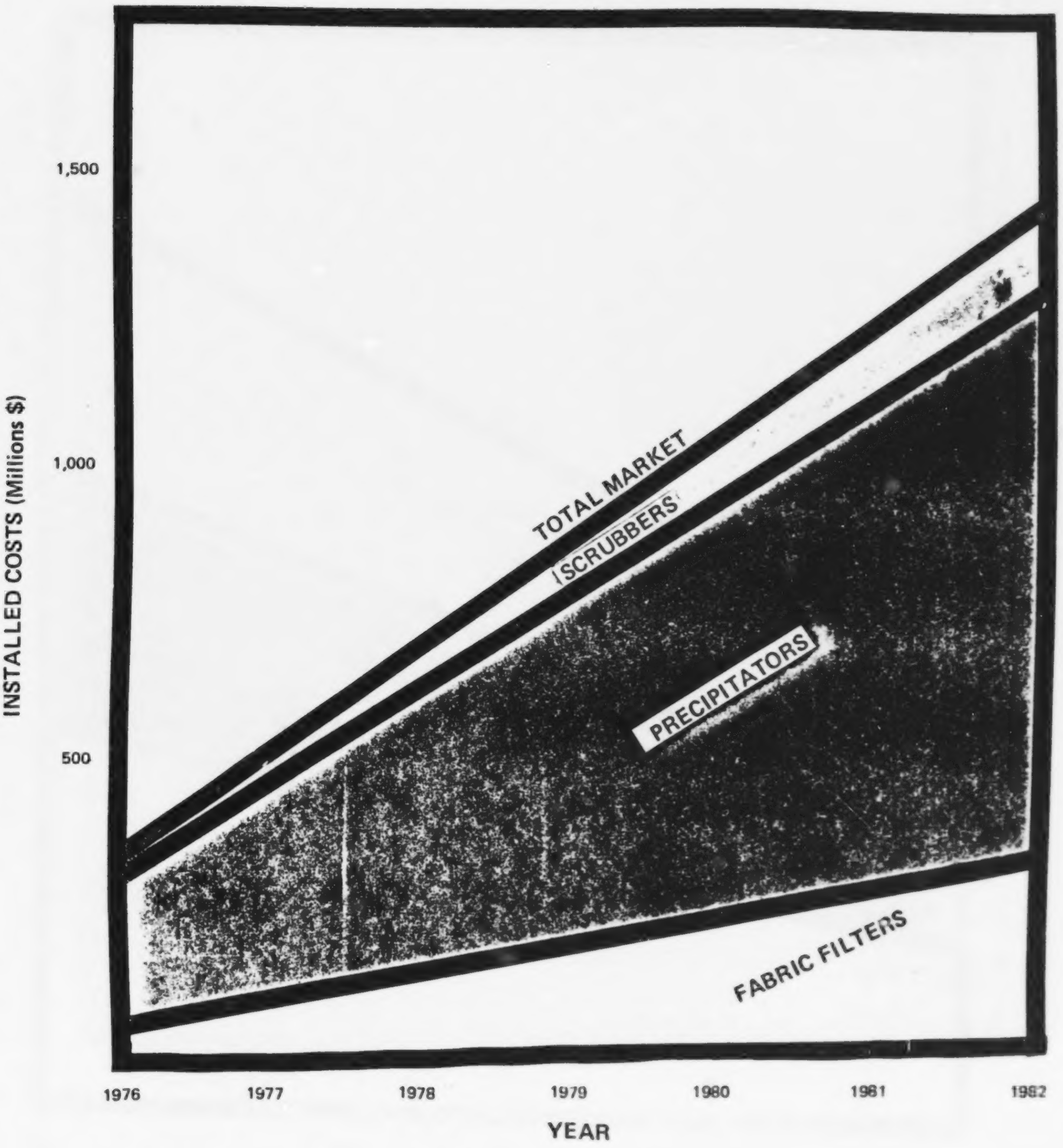
SUMMARY

The U.S. market for air pollution control equipment in perspective with the entire world is a huge market, and it will expand very rapidly. Scrubbers for SO_2 removal will represent the largest segment of this expansion, and the individual market share for precipitators, scrubbers and fabric filters could be greatly affected by technology and legislative changes. The McIlvaine Company recently conducted a study for a client on the worldwide precipitator market and determined that the U.S. purchases approximately 35% of all the precipitators used in the world. Although we have not yet done a study on other types of equipment used worldwide, we suspect that an equally large or even larger percentage of flue gas scrubbing systems will be purchased for utilities in the U.S., and even though a smaller percentage of fabric filters will be purchased by U.S. companies, as much as one-third of all the air pollution control equipment in the world will be purchased in the U.S. in the next decade.

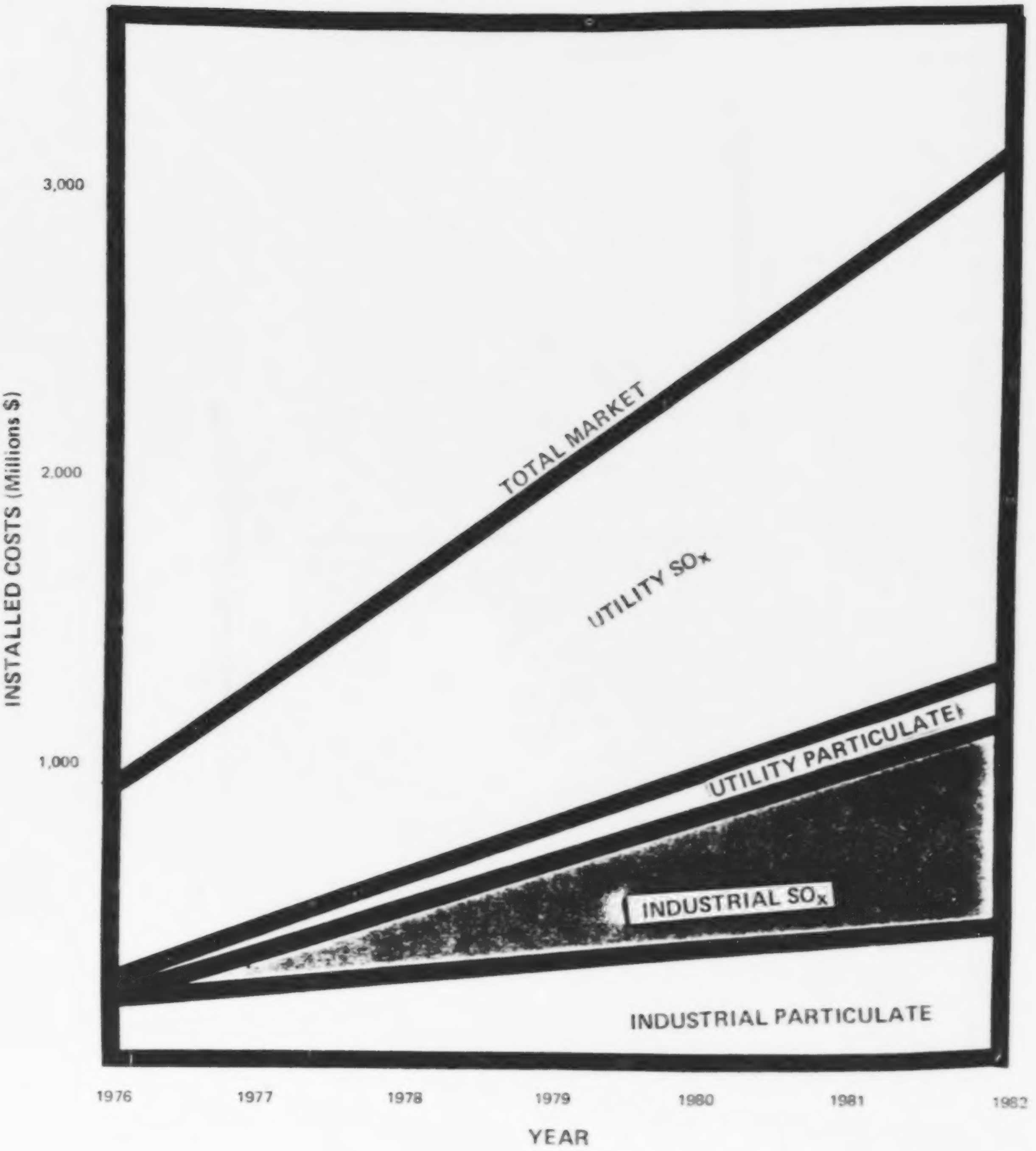
GRAPH 1 – INDUSTRIAL SECTOR



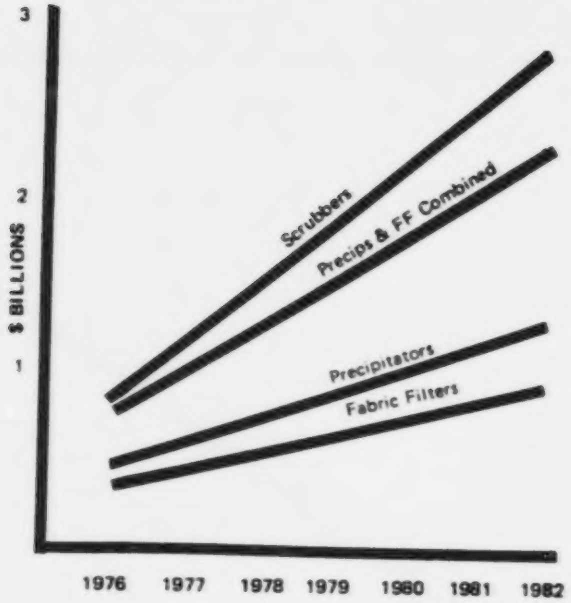
GRAPH 2 – UTILITY PARTICULATE



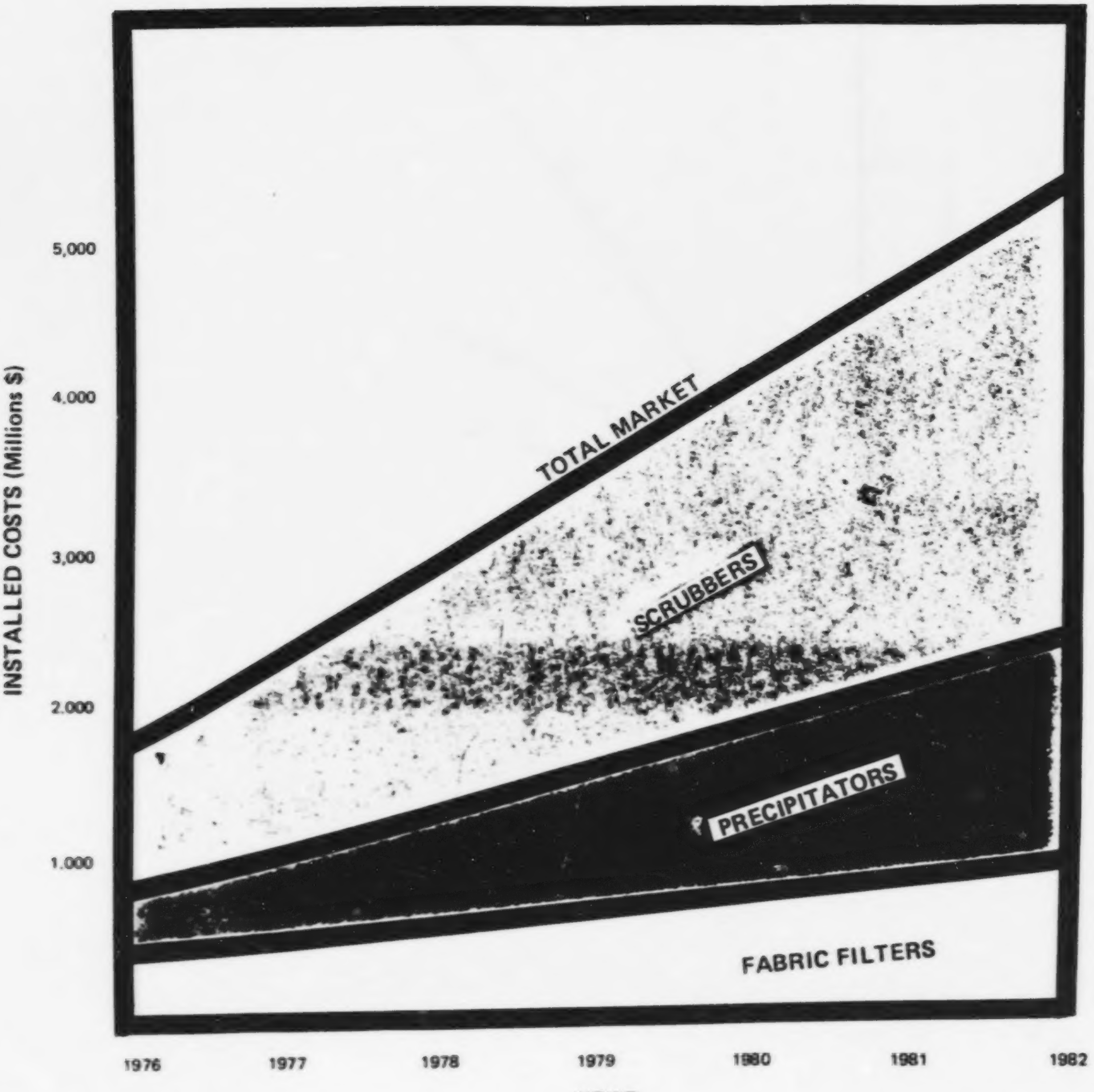
GRAPH 3 – SCRUBBER MARKET



GRAPH 4
ORDERS FOR AIR POLLUTION CONTROL EQUIPMENT

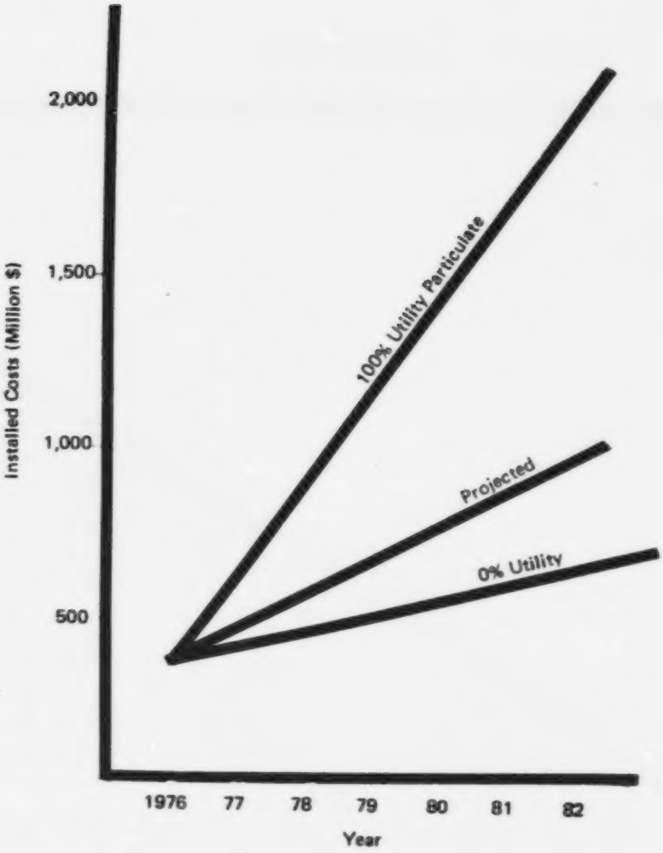


GRAPH 5 — TOTAL MARKET



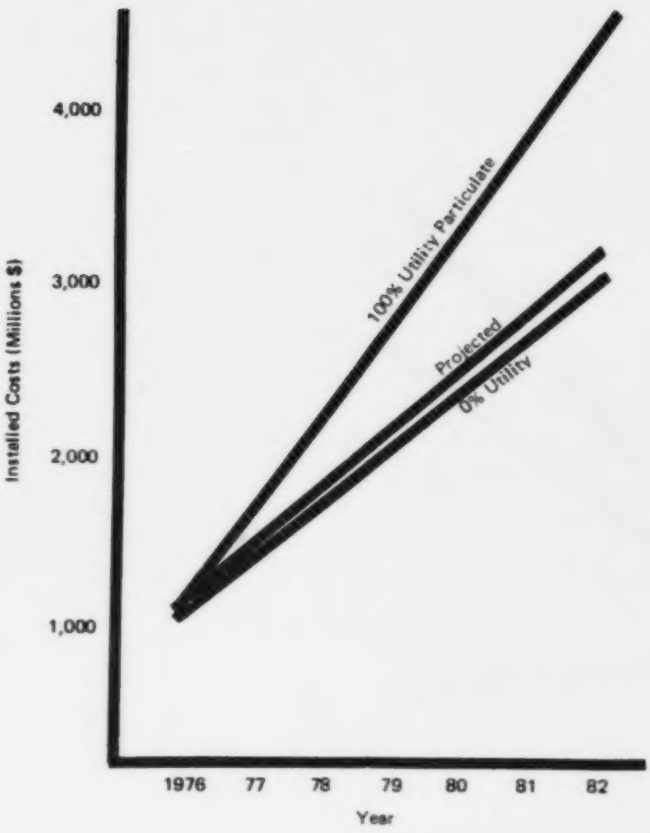
GRAPH 6

EFFECT OF UTILITY SEGMENT ON FABRIC FILTER SALES



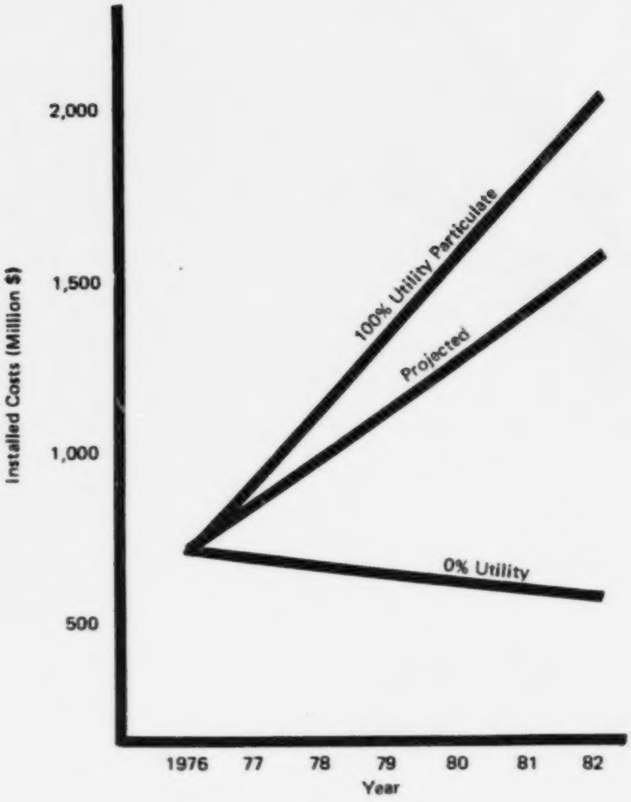
GRAPH 7

EFFECT OF UTILITY SEGMENT ON PARTICULATE SCRUBBER SALES



GRAPH 8

EFFECT OF UTILITY SEGMENT ON PRECIPITATOR SALES



DUST EMISSION CONTROL FOR STATIONARY SOURCES IN THE FEDERAL REPUBLIC OF GERMANY: STANDARDS OF PERFORMANCE, BEST AVAILABLE CONTROL TECHNOLOGY AND ADVANCED APPLICATIONS.

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LEGAL SITUATION

National standards of emission for gaseous and particulate pollutants had for the first time been established in 1964 by the "Technical Instruction for Maintaining Air Purity (TI-Air 64)", an administrative regulation under the "Gewerbeordnung" (Industrial Inspection Law). After promulgation of the Federal Immission Control Law in 1974 the TI-Air has been amended and decreed as "First General Administrative Regulation under the Federal Immission Control Law" (TI-Air 74).[1,2]

The TI-Air 74 provides standards of performance to stationary industrial sources, subject to licensing, and some ambient air standards.

The standards of emission are primarily applicable to new sources and to those existing sources, which shall be significantly modified. But, by the instrument of Subsequent Directives, the standards may also be applied to any existing source if the purpose of the Immission Control Law is not attainable otherwise. Whether Subsequent Directives be imposed is left to the discretion of the competent authority. The standards of performance are defined thus, that they may be met by application of the best available control technology. The Immission Control Law entitles the competent authority to require attainment of deviating emission levels - in particular those below the TI-Air standard - if this is indicated by the actual state of the art of emission control.

The ambient air quality standards will be used as a criterion whether a new installation shall be installed. In general, the competent authority will not grant a license if exceeding of the respective air quality standard is being expected as a result of the new installation's emission.[3,4] Exceeding of the standard may be accepted during a definite transition period if, by shut down or significant improvement of existing installations, a final amelioration will be attained.

The TI-Air provides eight air quality standards on gaseous pollutants and two on particulates. The particulate standard are as follows:

Dust Sedimentation

- Annual arithmetic mean : 0.35 g/m^{3}d
- Maximum monthly arith. mean : 0.65 g/m^{2}d

Total Particulate Concentration (TSP)

- Annual arithmetic mean : 0.2 mg/m^3
- 95 % value* : 0.4 mg/m^3

Fine Particulate Concentration (< 10 μm)

- Annual arithmetic mean : 0.1 mg/m^3
- 95 % value* : 0.2 mg/m^3

* may be exceeded by 5 % of all values

Emission standards for particulates are provided for 35 stationary sources and 55 hazardous materials. The source-related standards range from 20 to 300 mg/m^3 (table 1) and the material standards, which are classified into three categories, are between 20 and 75 mg/m^3 (table 2).

If an operation may neither be exactly identified by material nor by the affected facility the sliding scale provision according to graph 4 of table 1 becomes effective; this is the only provision of the TI-Air by which the fine particulate emission (< 10 μm) is restricted, too.

DEFINITION OF THE BEST AVAILABLE CONTROL TECHNOLOGY BY VDI-GUIDELINES

The VDI-guidelines, issued by the Verein Deutscher Ingenieure (German Engineer's Association) are conceived to define the best available technology for emission control. Though no legal instrument by itself they are a constituent part of the German air pollution control legislation. This is achieved by citing many of the guidelines within the scope of the TI-Air, as "defining the technical means for emission control". Any guideline provides comprehensive information on the process to be controlled, the measures for process-related emission reduction, the waste gas purification technology and recommendations on the attainable emission levels.

Table 3 gives a survey on those guidelines which are referred to by the TI-Air. Attention should particularly be directed to column three where the control devices are listed,with the rating being given to them by the guideline (paranthesis indicates lower rating). It is noticeable that in few cases cyclones have got the same or even higher rating as filters, EP's or scrubbers. This recommendation may sometimes be based on too optimistic assumptions in terms of raw gas dust load, fineness of dust and operation reliability, so that revision of the guideline should be required.

ACTUAL SITUATION ON PARTICLE EMISSIONS AND AMBIENT AIR QUALITY IN THE FEDERAL REPUBLIC OF GERMANY

Ambient air quality data of the Federal Republic are incomplete and the impact of control efforts on air purity therefore difficult to assess.

Dust sedimentation in the Ruhr-district, as the largest and most polluted industrial area had distinctly been decreasing from 0,5 g/m^2d in 1965 to 0,45 g/m^2d in 1970 and to 0,25 g/m^2d in 1976. But in the Saar-district, another heavy industries and mining area, there was only a minor decrease from 0,375 to 0,3 g/m^2d. Dust concentration is being monitored in the Ruhr-district, some large cities in other states and few rural areas since about 5 to 8 years. No data are available from most states before 1975.

A distinct decrease from some 140 to 100 $\mu g/m^3$ had been observed in the Ruhr-district between 1970 and 1975; the tendency was same in the other large cities. In contrast to this as slight increase on a 50 $\mu g/m^3$ level has been registered in rural areas. These results might be reassuring - but it should not be disregard that, according to recent findings on particle size distribution in ambient air aerosols 80 to 90 % of the particles are less than 10 μm in diameter [5]. This would mean that the ambient air standard to be effective (100 mg/m^3) could easily be exceeded if industrial production grows again.

Estimates on total dust emission from industry, traffic and domestic heating are quite inconsistent, too. This may be exemplified by the respective figures for the year 1970, which vary between 1.000.000 t [6] and 3.000.000 t [7] annually. Emission estimates, for industrial sources only, are listed in table 4 [6,7,8]. It may be drawn from this table that in 1975 combustion sources and steel production had contributed 1/3 each. The major uncertainty of these estimates is the extent to which fugitive sources (storage, shipping, roof ventilation) contribute to the respective industry's emission.

PRESENT STATE AND FUTURE REQUIREMENTS IN CONTROL TECHNOLOGY APPLICATION

1. Low and medium efficency control equipment (as cyclones and simple scrubbers) is still in use to many existing sources. The emission from those sources may average 2 to 4 the TI-Air standards.

2. Advanced high efficiency equipment as fabric filters and precipitators with large specific collection areas are being installed to new sources and those existing ones which are being updated by subsequent directives. These plants should meet the

TI-AIR standards or be slightly below.

3. For some new sources, emitting particularly hazardous materials, emission levels lower than the TI-Air standards are being imposed by the competent authorities. Increasingly also sources with a raw gas dust load only slightly above the actual performance standards have to become controlled. In both cases the costs are high compared to the gas flow or the amount of dust collected.
4. The number of installations with simultaneous gaseous and particulate emission control is increasing. As this trend is being accompanied by tougher requirements on waste water disposal the use of scrubbers is declining and more emphasis laid on dry scrubbing methods.

Two consequences can be drawn from these observations:

1. There is a need to have well-approved straightforeward control equipment available for retrofitting it to existing sources. This equipment has to be optimized to lower investment cost and energy consumption and to increase reliability. The control of existing sources with advanced equipment should contribute most to overall reduction of dust emission.
2. A wide panel of sophisticated specially designed control technologies - mainly based on fabric filters - is being required to control those sources where very low emission levels under unfavourable operation conditions shall be attained.

APPLICATION EXAMPLES

The following examples are typical for those advanced installations which meet tough performance standards even under critical conditions or those who are particularly interesting in terms of low energy consumption or under ecological categories.

1. WET ELECTROSTATIC PRECIPITATOR TO A TIN REFINING PROCESS

The refining facility consists of crucible furnaces in which the molten tin is treated with gaseous chlorine. The flue gas escaping from the furnaces contains tin- and zinc chloride and oxide and traces of chlorine; it used to be blended with the flue gases from a tinscrap melting furnace containing tin chloride and oxide and organic aerosols. The TI-Air restricte emissions of lead compounds to 20 mg/m^3, of zinc compounds to 50 mg/m^3 and of chlorine to 30 mg/m^3. It has been decided to install a wet electrostatic precipitator (WEP) because pilot-Venturi scrubbers and pilot dry electrostatic precipitators have not performed satisfactory.

The precipitator has parallel plates and rigid discharge frames. The internals are continously sprayed with water, whose pH is controlled by lime. Though all internals are made from stainless steel 316 a lifetime of 2 years may not be exceeded, due to the corrosion attack by chlorine. Therefore it is a major design feature that all internals are easily removable by the precipitator roof.

It may be gathered from table 5 that the clean gas dust concentration is less than 2 mg/m^3 and hence far below the design value of 20 mg/m^3. The chlorine concentration is some 10 mg/m^3 at pH 2,5. The capital expenditure is some \$ 25/(m^3/h). Because the tin is being recovered from the scrubbing liquor the operation expenses are negligible.

2. WET ELECTROSTATIC PRECIPITATOR TO AN ANODE BAKING FURNACE

Emission control of an anode baking furnace in a primary aluminum plant is another application of WEP's. The flue gas characteristics of such a furnace are listed in table 6. The design collection efficienies have been 90 % for SO_2, 95 % for HF and 97 % for tar. Two precipitators in line, one operating dry for tar collection only, and the second with continuosly spraying nozzles to remove gases and tar simultaneously have been installed. Both precipitators are of the parallel plate type, with plane collection plates and rigid discharge frames. The specific collection area is some 70 $m^2/(m^3/sec)$ in both precipitators. SO_2 - and HF removal is achieved by a double alcaline process; i.e. the primary (scrubbing) circuit operates with Na OH, which is being recovered by $Ca\ (OH)_2$ in the secondary (water treatment) circuit.

The built-up problem which has been encountered after start up has been solved by both, treating the recovered Na OH-solution with flue gas from the furnace and by operating the primary circuit at pH 5 to 6. The improvements due to flue gas introduction into the Na OH-liquor can be attributed to Ca CO -formation in the recovery vessel and subsequently lowering of the Ca-ion concentration in the recovered Na OH.

Corrosion, another serious problem, has been prevented by lining the casing with fiber glass coating and replacement of the mild steel internals by those from stainless steel.

The price for such an installation, comprizing conditioning tower, wet and dry precipitators, induced draft fan and ductwork is about \$ $35/(m^3/h)$. Inclusion of the water treatment system will raise the price to \$ $50/(m^3/h)$. Energy consumption without water treatment system is some 2,8 kWh/1000 m^3 and with water treatment system some 3,3 kWh/1000 m^3. The scrubbing system works on a closed circuit, so that no waste water problem is incident to it.

3. FABRIC FILTER TO A GLASS FURNACE

The use of dry agents to render possible dust release from fabric filter bags has been successfully tested at the emission control system of a glass melting furnace.

The need to develop this technology occured when dedusting of flue gases from a lead-boron-silicone glass furnace turned out to be impossible because the bags of a conventionally operated fabric filter have been clogging rapidly. Because the feed of additives to the flue gas seemed to be a suitable approach a pilot study has been conducted, during which dolomite, calciumhydroxide and alumina have been tested. These materials had been chosen because they serve as feed for the glass furnace. It turned out that only alumina can be used and the full size unit is being operated with this material (table 7).

Major components of the installation are a plate cooler (to reduce the gas temperature from 700°C to 200°C), two pulse jet filters in parallel and the additive-dosing system. Each of the filters is capable to handle the total gas flow. The additive is fed into the gas before the cooler. The dust concentration of the raw gas is some 0.5 to 0.7 g/m^3; it is encreased by the additive to 4 to 6 g/m^3. The clean gas dust concentration is less than 5 mg/m^3 (compared to the TI-Air standards of 20 mg/m^3 and 75 mg/m^3 for lead and boron, respectively).

Electron-microscope photographs have revealed that the submicron lead-boron-oxide sublimates are aggregated to the 10 to 30 μm alumina particles. This may explain the excellent performance of the installation. The pollutant-loaden alumina is being fed into the furnace so that no disposal problem results from the system. Capital expenditure is $ 35/(m^3/h).

4. ELECTROSTATIC PRECIPITATORS TO UTILITY POWER STATIONS

The TI-Air rules that for coal-fired boilers with a gas flow of more than 500.000 m^3/h (equivalent to some 120 MW) the emission standard of 150 mg/m^3 must be met, even if one field of each parallel section is out of service. Some precipitators to 700 MW-boilers have been constructed under consideration of the new ruling. Their main characteristics are:

- 4 fields in series
- 4 or 8 parallel sections (16 to 32 HV-groups)
- up to 15 m collection plate hight
- rigid discharge frames
- 280 to 300 mm passage width

Another feature of these precipitators is their thorough design, for which the warranty requirements on electrode life time may be an indication: no more than 8 wire ruptures (0.012 %) during the first year of operation are accepted for installation I and not more than 10 ruptures (0.01 %), for two years, with installation II (table 8). It may be gathered from table 8 that the actual performance of both precipitators is much better than anticipated; this is particularly remarkable for installation II in which low sulfur coal is fired.

Capital expenditure for those installations,including fans, ductwork and errection, but no foundations and dust conveying systems, is some \$ 6/(m^3/h). The present 700 MW dry bottom boilers have been preceeded in the early 70ties by 350 MW wet bottom boilers. The precipitators to those installations have also been designed to meet the 150 mg/m^3 standard, but with only two fields in series and spec. collection areas of some 75 m^2/(m^3/sec). As the emission was considerably above the standard a third field had been retrofitted, increasing the collection area to some 100 m^2/(m^3/sec). It has been revealed that even this area was hardly enough to yield the design efficiency. This experience may have contributed to the comparably conservative sizing of the "new generation".

R & D ACTIVITIES

The R & D Activities on dust collection technology - as funded by the Umweltbundesamt - are strongly application related.

Major objectives of the various projects are the reduction of overall expenditure and energy consumption of existing control equipment and extension of the fabric filter application range to those sources which have so far been uncontrolled or only been controlled by low efficiency equipment.

As to electrostatic precipitators it shall be evaluated whether farther sectionalization could be a means to increase overall migration velocity. For this purpose field measurement of the sparkover Voltage distribution in power station precipitators will be conducted and the feasibility of appropriate design modifications be studied.

Within the scope of a second experimental project on precipitators the influence of passage width on migration velocity is being studied. This investigation has mainly been initiated to prove preliminary findings of researchers and a precipitator manufacturer predicting an increase of migration velocity with passage width (at constant field strength). Maximum passage width will be 750 mm. Voltage may be increased to 150 kV. Confirmation of the so far promising results would offer an interesting approach to lower the overall expenditure of precipitators.

Scrubbers, in particular Venturis shall be optimized by means of pilot tests at industrial sources, mainly in the metallurgical industry. The major design features to be varied are throat shape and water supply configuration. Collection efficiency and power requirement in dependence on operation mode and design are studied. In addition criteria for the transfer of pilot results to full size units shall be developed.

Another pilot investigation is being conducted with fabric filters. This project has mainly been conceived to extend the application range to new sources in the metallurgical and chemical industry and to industrial coal- and oil-fired boilers. Other objectives are evaluation of efficiency versus service time of bags and mode of bag cleaning.

Any of these projects has been conceived not only to improve the control technology but also to produce data on fine particle emission from industry. This shall be achieved by using cascade impactors.

Medium term research priorities will be identification and evaluation of fugitive sources and their control, stepwise replacement of water polluting control equipment and development of highly reliable and efficient standard control equipment for application to existing sources.

REFERENCES

/1/ Bundes - Immissionsschutzgesetz - BImSchG vom 15. März 1974 (Bundesgesetzblatt Teil I S. 721, 1193)

/2/ Erste Allgemeine Verwaltungsvorschrift zum Bundesimmissionsschutzgesetz vom 28. August 1974 S. 426, 452

/3/ Feldhaus, BImSchR, Bd. 1, Randnote 1 zu Nr. 2.4.1 TA-Luft

/4/ H.-L. Dreissigacker, Übergeordnete Gesichtspunkte zur Frage der Emissionsminderung unter besonderer Berücksichtigung der Rauchgasentschwefelung, Sonderdruck der Fa. Walther & Cie. AG, Köln, 1978

/5/ Laskus, L. und E. Lehmann, Korngrößenverteilungen von Stäuben im Rauchgas von Kraftwerken und in atmosphärischer Luft, Staub-Reinhalt.Luft 37 (1977) Nr. 4, S. 136/140

/6/ Materialien zum Immissionsschutzbericht 1977 der Bundesregierung an den Deutschen Bundestag, Erich Schmidt-Verlag, Berlin 1977

/7/ Brocke, W., Immissions-Situation aus der Sicht der Emission, Staub-Reinhalt. Luft 34 (1974) Nr. 9 S. 329/332

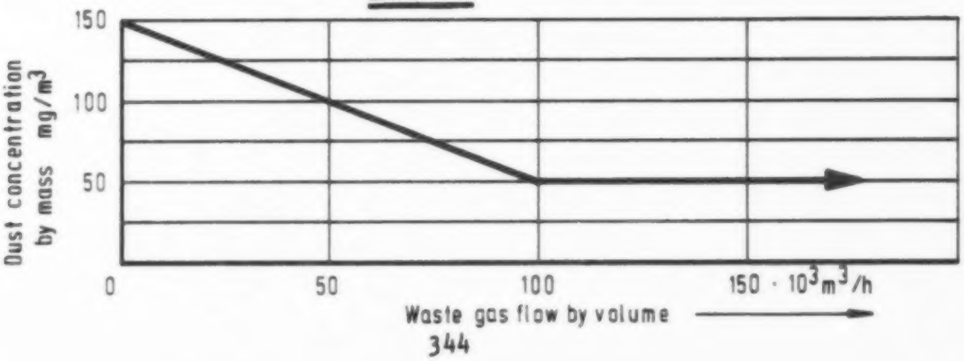
/8/ Umweltgutachten 1978 des Rates von Sachverständigen für Umweltfragen

Table 1. **NEW SOURCE STANDARDS OF PERFORMANCE FOR PARTICLE EMISSIONS IN THE FEDERAL REPUBLIC OF GERMANY**

AFFECTED FACILITY	EMISSION LEVEL*
BOILERS FOR SOLID FUEL	
-- Fire tube boilers	300 mg/m^3
-- Water tube boilers	
-- gas flow less than 5 x $10^5 m^3$/hr	150 mg/m^3
-- gas flow more than 5 x $10^5 m^3$/hr	Coal 150 mg/m^3 Lignite 100 mg/m^3
Values corrected to:	
- 13 % O_2 for Wood-fired boilers	
- 7 % O_2 Coal fired fire-tube and water tube boilers with stoker-firing	
- 6 % O_2 Coal fired water tube boilers with dry slag discharge	
- 5 % O_2 Coal fired water tube wet bottom boilers	
OIL-FIRED BOILERS	
gas flow more than 10^5 m^3/hr ...	50 mg/m^3
less than 10^5 m^3/hr ...	See Graph 1
values corrected to 3 % O_2	

*Emission levels in mg per dry standard cubicmeter, if not otherwise stated

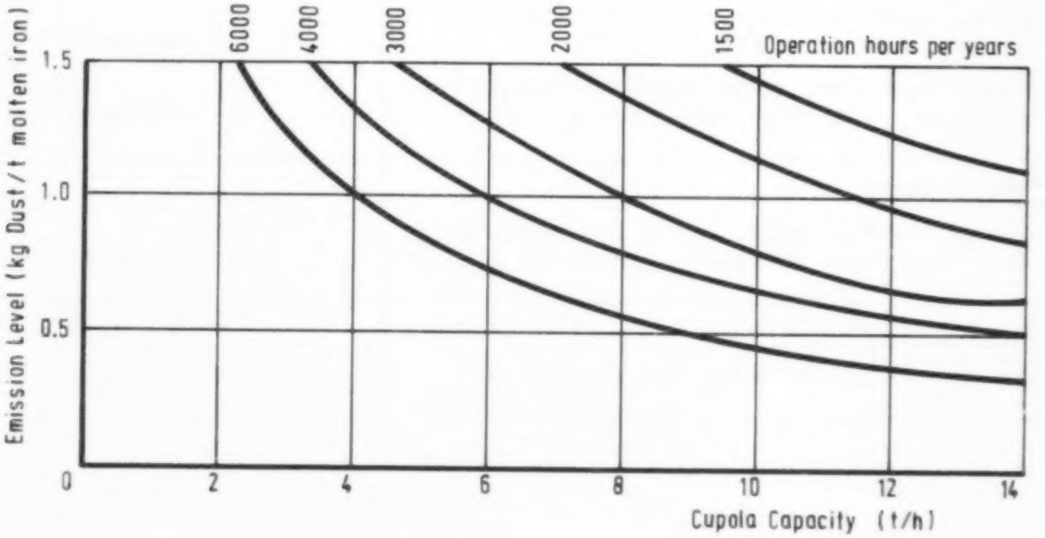
GRAPH 1



AFFECTED FACILITY	EMISSION LEVEL
GAS-FIRED BOILERS FOR BLAST FURNACE GAS	50 mg/m^3
INCINERATORS	
corrected to 11 % O_2 0.75 ton/hr to 17 % O_2 0.75 ton/hr	100 mg/m^3 * wet Ringelmann < 1
* Also during soot-blowing operation	
MUNICIPAL AND INDUSTRIAL WASTE PREPARATION	150 mg/m^3
SHREDDER PLANTS	100 mg/m^3
ROCK PREPARATION	
- Dryers and Bloating Facilities for Slate and Clay (corrected to 3 % CO_2)	150 mg/m^3
- Dolomite and Lime Calcination Furnaces	150 mg/m^3
- Gypsum Calcination Furnaces	150 mg/m^3
- if baghouses are applied	75 mg/m^3
CEMENT PLANTS	
- Facilities with other than electrostatic dedusting equipment	75 mg/m^2
- Facilities being generally dedusted by EP's, such as Kilns, Clinker Coolers, Dryers, Grinding Dryers	120 mg/m^3
- Facilities with electrostatic dedusting equipment but high resistivity dust	150 mg/m^3
CERAMIC WORKS	
- Calcining Furnaces, where dry scrubbing for fluorides emission control is applied	150 mg/m^3
PIG IRON BLAST FURNACES	20 mg/m^3
- if the blast furnaces gas is flared	50 mg/m^3

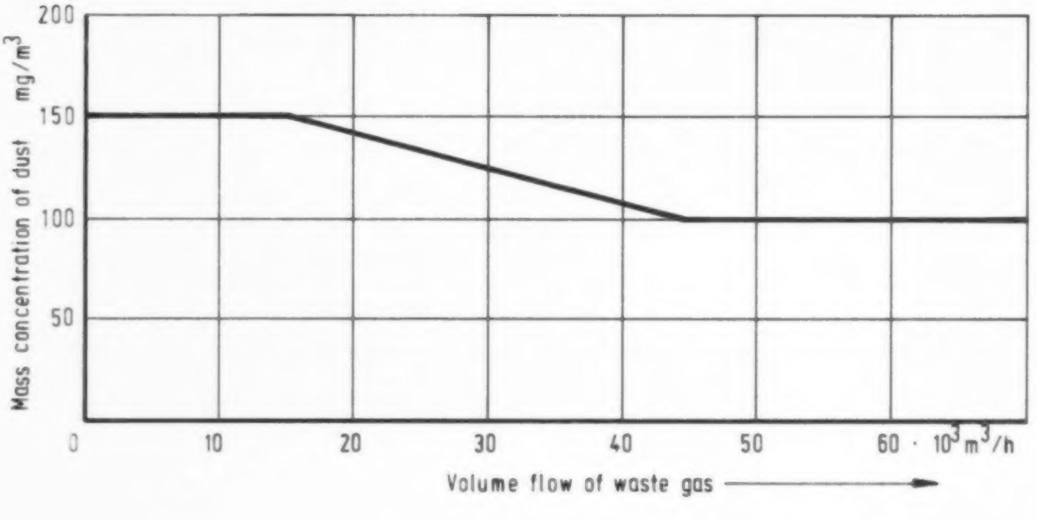
AFFECTED FACILITY	EMISSION LEVEL
PRIMARY LEAD SMELTERS	20 mg/m^3
IRON ORE SINTERING PLANTS	
- Crude phosphate concentrates	75 mg/m^3
STEEL WORKS	
- Converters, Electric Arc Furnaces Vacuum Melting Furnaces	150 mg/m^3
- Secondary Electroslag Furnaces	150 mg/m^3
- Scarfing Machines	150 mg/m^3
SECONDARY ALUMINUM SMELTERS	75 mg/m^3 Ringelmann < 1
Secondary Smelters for NON-FERROUS METALS and their ALLOYS (Secondary Aluminum Smelters excluded)	75 mg/m^3 Ringelmann < 1
CUPOLAS	
- capacity < 14 ton/hr ...	See Graph 2
- capacity > 14 ton/hr ...	0.250 kg/ton

GRAPH 2



AFFECTED FACILITY	EMISSION LEVEL
Foundries for STEEL, IRON, NON-FERROUS METALS	100 mg/m^3
SULFURIC ACID WORKS	Particulate Emission Control required
ALUMINUM PLANTS	
- Aluminum Oxide Calcining Furnaces	150 mg/m^3
- Primary Aluminum Reduction Plants	20 kg Dust/t Aluminum
CORUNDUM PLANTS	
- Calcining and other Furnaces	150 mg/m^3
CALCIUM CARBIDE PLANTS	
- Furnaces	150 mg/m^3
FIBERBOARD PLANTS	
- Grinding and Air Conveying	50 mg/m^3
- Chip Dryers	150 mg/m^3
- Wood processing operations not otherwise specified ...	See Graph 3

GRAPH 3



AFFECTED FACILITY	EMISSION LEVEL
COKE OVEN PLANTS	
- Charging Operation	collection efficiency 90 %
- Coke Discharge (push side)	control required, but efficiency not specified
ASPHALT PLANTS	
- Rock Dust Rotary Dryers (corrected to 4 % CO_2)	100 mg/m^3
ANODE BAKING FURNACE	150 mg/m^3
GLASS PLANTS	
- Furnaces	150 mg/m^3
Grinding, Air Conveying, Classifying and Packing Operations	
- Mass flow < 3 kg/hr	150 mg/m^3
- Mass flow > 3 kg/hr	75 mg/m^3
ANY COMBUSTION PROCESS, unless otherwise specified	Ringelmann < 2
ANY OPERATION, unless otherwise specified	See Graph 4

GRAPH 4

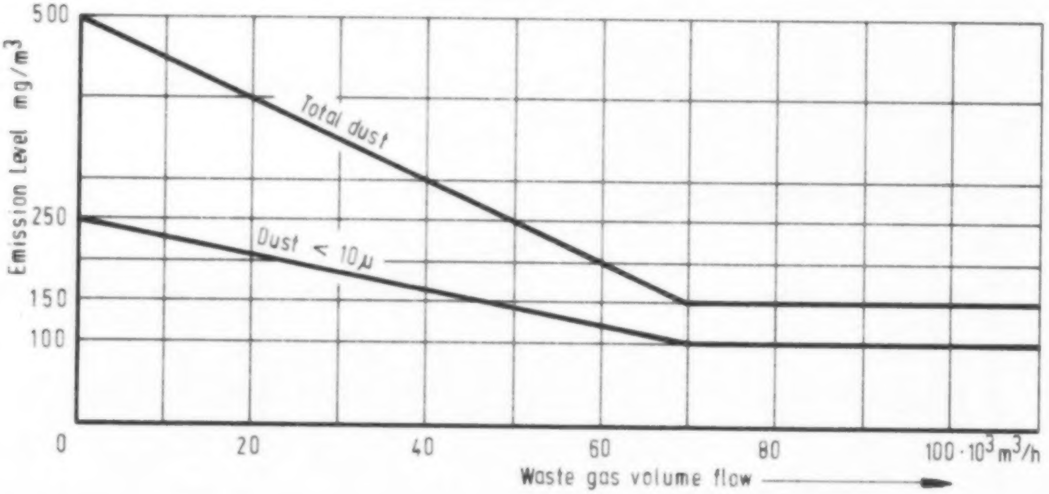


Table 2. EMISSION STANDARDS FOR PARTICULAR MATERIALS IN THE FEDERAL REPUBLIC OF GERMANY

Category I ($\dot{m}$> 0.1 kg/h) Em. Std. ≤ 20 mg/m^3

Category II ($\dot{m}$> 1 kg/h) Em. Std. ≤ 50 mg/m^3

Category III ($\dot{m}$> 3 kg/h) Em. Std. ≤ 75 mg/m^3

Material:	Category:
Aluminum carbide	III
Aluminum nitride	III
Ammonium compounds	III
Antimony and its soluble compounds *)	II
Arsenic and its soluble compounds *)	I
Asbestos	I
Barium sulfate	III
Barium compounds if soluble *)	II
Beryllium and its soluble compounds *)	I
Bitumen	III
Boron trifluoride	II
Boron compounds, if soluble *)	III
Lead and its soluble compounds *)	I
Cadmium and its soluble compounds *)	I
Calcium arsenate	I
Calcium cyanamide	III
Calcium fluoride	II
Calcium hydroxide	III
Calcium oxide	III
Chromium compounds, if hexavalent	I
Cristobalite with particles smaller than 5 μm	II
Fluorine compounds, if soluble *)	I
Fluorspar	II

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*) Soluble compounds are those materials which are soluble in the respiratory and digestive tracts, on the surface of the skin or in the absorbing organs of plants to such a degree that they can cause hazardous effects.

Material:	**Category:**
Iodine and its compounds	II
Diatomaceous earth	II
Cobalt and its compounds	II
Copper and its soluble compounds *)	III
Copper fume	I
Magnesium hydroxide	III
Magnesium oxide	III
Molybdenum and its soluble compounds *)	III
Nickel	I
Nickel carbonate	I
Nickel oxide	I
Nickel sulfide	I
Phosphates	III
Phosphorus pentoxide	I
Quartz with particles smaller than 5 µm	II
Mercury and its compounds, except cinnabar	I
Soot	II
Selenium and its soluble compounds *)	I
Silver compounds, very soluble, e.g. silver nitrate *)	II
Ferrosilicon	III
Silicon carbide	III
Strontium and its compounds	II
Tar	II
Cutback pitch	II
Tellurium and its soluble compounds *)	I
Thallium and its compounds	I
Tridymite with particles smaller than 5 µm	II
Uranium and its compounds	I
Vanadium and its compounds	I
Bismuth	III
Tungsten and its compounds, except tungsten carbide	III
Zinc and its compounds	II
Dusts of organic compounds, e.g. anthracenes, aromatic amines, 1,4-Benzoquinone, naphtalene	II

TABLE 3. VDI - GUIDELINES ON DUST EMISSION CONTROL

AFFECTED FACILITY - Guideline Number / Issue Date -	Raw Gas Dust Conc. /g/m³/	Control Device	Emission Level VDI-Guideline	/mg/m³/ TI - Air
WATER TUBE BOILERS FOR SOLID FUEL - VDI 2091 / 11.1975 (Draft) -				
- Coal				
-- Gas flow 50,000 m³/h	2 - 5	CYC, (EP)	300 *	150
-- 50,000 to 500,000 m³/h	5 - 20	EP, (CYC)	150	150
-- 500,000 m³/h	5 - 35		150	150
- Lignite				
-- Gas flow 50,000 m³/h		CYC, (EP)	300 *	150
-- 50,000 to 500,000 m³/h	2 - 10	EP, (CYC)	100	150
-- 500,000 m³/h	3 - 30		100	100
* If cyclones are used, this value may be exceeded during sootblowing operation				
FIRE TUBE BOILERS - VDI 2300 / 12.1975 (Draft) -	0,5 - 2	CYC	300	300
OIL FIRED BOILERS - VDI 2297 / 8.1975 (Draft) -				
- Gas flow 0 to 100,000 m³/h**		CYC, EP	150** to 50	** 150 to 50
- 100,000 m³/h		NONE*	50	50
* No control device required, if ash content below 0,05 % ** Sliding scale provision				

TABLE 3 VDI - GUIDELINES ON DUST EMISSION CONTROL

AFFECTED FACILITY	Guideline Number Issue Date	Raw Gas Dust Conc. /g/m³/	Control Device	Emission Level /mg/m³/	
				VDI-Guideline	TI - Air
WASTE INCINERATORS 750 kg/h	VDI 2301 11. 1975	3	CYC, (F,EP)	100	100
WASTE INCINERATORS 750 kg/h	VDI 2114 12. 1974		F, EP, (S)	100*	100**
* Ringelmann <1 attainable ** Ringelmann <1 required					
INCINERATORS FOR OIL-CONTAINING WASTE	VDI 3460 12.1974 (Draft)		EP, (F*, S)	100	-
* Fabric filters if elevated heavy metals concentration					
ROCK GRINDING AND CLASSIFYING	VDI 2504 2.1978		F, S	75	75 150*
* Mass flow<3 kg/h					
CEMENT WORKS	VDI 2094 3. 1978 (Draft)				
- Kilns, dryers, clinker coolers			EP (CYC*)	120	120
- As above, but aggravated conditions for EP's			EP	150	150
- Facilities with other than EP's			F	75	75
* Admitted for grate-coolers at favourable conditions					

TABLE 3 VDI - GUIDELINES ON DUST EMISSION CONTROL

AFFECTED FACILITY	Guideline Number / Issue Date	Raw Gas Dust Conc. $/g/m^3/$	Control Device	Emission Level $/mg/m^3/$	
				VDI-Guideline	TI - Air
CERAMIC INDUSTRY STONEWARE, BRICKS ETC.	VDI 2585 / 8.1976 (Draft)				
- Grinding, Conveying			F, (CYC,EP)	75	75
- Furnaces			F, (CYC,EP)	75	150
- Bloating of clay and shale			F, (CYC, EP)	150	150
BLAST FURNACES	VDI 2099 / 2.1959	10 - 50	S, (EP-wet)	20	20
* If blast furnace gas is flared					50*
LEAD WORKS	VDI 2285 / 12. 1975	2 - 75	F, S, (EP)	20	20
CUPOLAS	VDI 2288 / 9. 1971				
- Depending upon capacity and annual operation time		6 - 12	F, S, EP	0.5 - 1.5 kg/t	0.5-1.5 kg/t
- Capacity >14 t/h					0.25 kg/t
BASIC OXYGEN FURNACE	VDI 2112 / 6. 1966	5 - 50	F, S, EP	150	150
ELECTRIC ARC FURNACE	VDI 3465 / 10. 1975	3 - 15	F, EP, (S)	75	150

TABLE 3. VDI - GUIDELINES ON DUST EMISSION CONTROL

AFFECTED FACILITY	Guideline Number / Issue Date	Raw Gas Dust Conc. /g/m^3/	Control Device	Emission Level /mg/m^3/	
				VDI-Guideline	TI - Air
ALUMINUM WORKS	VDI 2286 / 3. 1974				
- Grinding			EP, S	75	75
- Calcining				150	150
- Reduction Furnace				75	20 kg/t
CALCIUM CARBIDE PLANTS	VDI 2111 / 12. 1965	0.2 - 2.5	S, (F)	350 *	150 ***
* Furnaces, ** Preparation *** Furnaces				150 **	
ASPHALT PLANTS	VDI 2283 / 12. 1974	20 - 500	S, F, (CYC)	100 *	100
* Dryers, if CO_2 content above 4 % ** Other operation than dryers *** Recommended				75 **	75 ***
GLASS PLANTS	VDI 2587 / 7.1967 (Draft)		F		
- Reverberatory Furnace, fuel-heated, at mass flow <4.5 kg/h				250 *	150
- Reverberatory Furnace, fuel-heated, at mass flow > 4.5 kg/h				150 **	150
- Reverberatory Furnace, electrical heating				200 mg/kg***	150
- Transport, Preparation, Pulverizing				75	150

* 250 mg/m^3 reasonable, though 100 mg/m^3 attainable
** 150 mg/m^3 reasonable, though 100 mg/m^3 attainable
*** Dust concentration shall not be higher than for fuel heated furnaces

Table 3. VDI - GUIDELINES ON DUST EMISSION CONTROL

AFFECTED FACILITY – Guideline Number / Issue Date –	Raw Gas Dust Conc. /g/m^3/	Control Device	Emission Level VDI-Guideline	/mg/m^3/ TI - Air
COKE OFEN WORKS -PREPARATION OF COAL AND COKE - – VDI 2100 / 6. 1976 (Draft)		CYC combined with S, (F)	75	75 * 150 *
* 75 mg/m^3 at massflow > 3 kg/h, 150 mg/m^3 at massflow < 3 kg/h				
COKE OFEN WORKS - BATTERY - – VDI 2302 / 8.1970 (Draft) –				
- Charging hole emissions ...		S	90% coll.eff.	90% coll.eff
- Push side emissions ...			no provision	*
* Emission control required, but performance not specified				
COPPER WORKS – VDI 2101 / 9. 1966 –		EP, F, (CYC)	300	*
* refers to VDI 2101, VDI 2102, VDI 2287				
WOODWORKS – VDI 3462 / 3. 1974 –	10 - 400	CYC, F, (S)		
Polishing operations			50	50
Chipdryers			150	150
* Any other operation with particulate massflow <3,5 kg/h sliding scale provision				
** Any other operation: sliding scale provision			150* - 100*	150**-100**

Table 4. DUST EMISSION FROM INDUSTRIAL SOURCES IN THE FRG

	1970 /Kt/a/		1974/75 /Kt/a/	
Fuel Combustion (Power & Heating)	465		270	
Utilities - Coal		210		100
- Lignite		80		70
- Oil		20		15
Industry - Coal		70		20
- Lignite		30		15
- Oil		55		50
Waste Incineration	65		65	
Stones, Earths, Ceramics	110		70	
Cement		65		30
Lime & Gypsum		20		20
Asphalt Plants		20		15
Glass, Ceramics		5		5
Iron & Steel	290		280	
Pig Iron		20		15
Converters, BOF's, Open Hearth F's		70		40
Sintering		50		40
Ore Preparation		150		185
Non Ferrous Metals	15		20	
Aluminum		10		15
Chemical Industry	20		15	
Mining of Lignite, Coal, Potassium	50		35	
	1015		755	

Table 5. WET ELECTROSTATIC PRECIPITATOR TO A TIN REFINERY PROCESS

	WEP Inlet	WEP Outlet
Gas Flow /m^3/h/	10,000	10,000
Gas Temperature /°C/	60	30
Design Dust Concentration /mg/m^3/	2,000	20
Actual Dust Concentration /mg/m^3/	max. 2,000	2

Spec. collection area /m^2/(m^3/sec)/: 75

Spec. filter current /mA/m^2/ : 0.4

N°. of fields in series /-/ : 2

Liquid to gas ratio /ltr/m^3/ : 1.5

Energy consumption /kWh/1000 m^3/ : 1.8

Table 6. ANODE BAKING-FURNACE EMISSION CONTROL BY DRY (TAR) AND WET EP IN LINE

		Tar Precip. Inlet	WEP-Inlet	WEP Outlet
Gas Flow	$/m^3/h/$	40,000	40,000	40,000
Gas Temp.	$/^oC/$	110	80	45
SO_2	Design $/mg/m^3/$	1,000	1,000	100
	Actual $/mg/m^3/$	1,000	-	40 - 80*
HF	Design $/mg/m^3/$	100	100	5
	Actual $/mg/m^3/$	-	-	2 - 3*
Tar	Design $/mg/m^3/$	1,500	100 - 200	20 - 30
	Actual $/mg/m^3/$	1,500	-	50
Dust	Design $/mg/m^3/$	150	-	50
	Actual $/mg/m^3/$	-	-	15

Liquid to Gas Ratio of WEP $/ltr/m^3/$: 1,25

* depending on pH-value

Table 7. FABRIC FILTER TO A GLASS FURNACE

Gas Flow	/Am^3/h/*	: 2,820
Temperature before cooler	/^{0}C/	: max. 700
Temperature before filter	/^{0}C/	: 200
Dust concentration before filter	/mg/Am^3/	: 500
Dust concentration after filter	/mg/Am^3/	: < 5
Differential pressure	/Pa/	: 1,100
Pulse air consumption	/Nm^3/h/	: 10
Pulse air pressure	/bar/psig/	: 4/ ~60
Filter rate	/m^3/(m^2/min)/	: 1.8
Bag material	: TEFLON needle felt	
Energy consumption (total)	/kWh/1000 Am^3/	: 3.9
Energy consumption (main fan)	/kWh/1000 Am^3/	: 1.3
Energy consumption (pulse air)	/kWh/1000 Am^3/	: 1.0
Energy consumption (cooler fans)	/kWh/1000 Am^3/	: 1.6
Adsorbent (for additive) : Alumina ($Al_2O_3 \times H_2O$)		
Adsorbent conc. before cooler/filter	/g/Am^3/	: 3.5 - 5.3
Adsorbent flow (recirculated)	/kg/h/	: 10 - 15
Adsorbent (feed and bleed off)	/kg/h/	: 1 - 3

* Actual Cubicmeter per Hour

Table 8. ELECTROSTATIC PRECIPITATOR TO UTILITY POWER STATIONS

Installation			Weiher III	Wilhelmshaven
Rated Power		/MW/	650	720
Sulfur Content of Coal		/%/	1	0.6
Spec. collection area		$/m^2/(m^3/sec)/$	155	135
N^o of sections in parallel		/-/	4	8
N^o of fields in series		/-/	4	4
N^o of high Voltage groups		/-/	16	32
Dust conc. upstream ESP				
	Design	$/g/m^3/$	15	15
	Actual	$/g/m^3/$	5	5
Dust conc. downstream ESP				
4 fields operating	Design	$/mg/m^3/$	45	-
	Actual	$/mg/m^3/$	30 - 40	10 - 50
3 fields operating	Design	$/mg/m^3/$	112	76
	Actual	$/mg/m^3/$	-	-
Plate hight		/m/	14.7	13
Passage width		/m/	0.3	0.3

ENGINEERING MANAGEMENT TRENDS IN THE DESIGN OF PRECIPITATORS AND BAGHOUSES

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ABSTRACT

This paper deals with organizational and economical aspects of managing a medium-sized engineering department devoted to the design of air pollution control systems with emphasis on turnkey projects for air pollution control.

Topics covered are the type of organization and problems associated with division of work by specialties versus task force project management; estimation of engineering cost; standardization against custom design; real cost of engineering, its components, managing overhead and cost of computer operations; managing development projects, laboratory work, model studies; recruiting and training engineering personnel; interfacing with customers and their A&E; monitoring engineering schedules and expenditures, reporting and forecasting; interfacing of engineering activities with other functions such as construction, service, testing and results, manufacturing and quality assurance; optimization techniques in pre-engineering and final design; reliability and liability responsibilities; too much or too little engineering work interfacing with sales and marketing; what is predicted for future trends in the engineering management of our industry.

The paper summarizes the experience of Western Precipitation Division of Joy Manufacturing Company in the management of a medium-sized engineering department charged with the design of reliable and economical precipitators, baghouses and scrubbers.

INTRODUCTION

The purpose of this paper is to present some of the organizational tools and economical aspects of problems encountered in the management of a medium-sized (100 to 125 people) engineering department involved exclusively with air pollution control systems.

Western Precipitation is a Division of Joy Industrial Equipment Company, a unit of Joy Manufacturing Company. Our corporate headquarters are located in Pittsburgh, Pennsylvania. Our division is located in Los Angeles, California, where all engineering activities take place. The reduced model of the organizational chart of our division reflecting the position of the engineering department in the operations group is illustrated in Figure 1.

Our main products are electrostatic precipitators on hot- and cold-side applications, various types of baghouses (fabric filters), scrubbers with varying designs and other types of air pollution control devices.

As of recent times, the main emphasis appears to be toward large turnkey projects in which our company responsibilities extend into the design, manufacturing and construction of the equipment providing the operation instruction and training of the plant maintenance personnel, participate in the start-up and testing of the unit throughout the system shakedown until the customer takes over a unit which has passed the removal efficiency specified and/or guaranteed by our contractual obligations.

In recent years, our main market has been in the utility business. Some of these units, both in the area of precipitators as well as in the fabric filters, represent multimillion-dollar projects of substantial commercial and engineering magnitude (see Figures 2, 3 and 4).

ORGANIZATIONAL ASPECTS

The engineering department is organized in what we consider at present time the best-suited arrangement to fulfill its function (Figure 5). Basically, all our activities take place in six main sections.

Project Engineering represents our external link with Contract Management and the customers or their consultants while internally assuring the interface of various disciplines from a technical, budgetary and schedular viewpoint.

The main responsibility of design integrity and economics as well as meeting our milestone dates rests with the Chief Discipline Engineers.

The Technology Section operates at the front end of our design effort as well as in solving various problems which occur during the design stage or troubleshooting of a reported equipment operational difficulty (deficiency report) where specialized effort is involved. In this section we have located the preparation of all general arrangements and flow diagrams as well as the proposal specialists' group. All engineering instruction sheets, which evolve from our proposal and specifications, are formulated here so that all executing disciplines have a clear picture of the job requirements, thus minimizing the number of interruptions as well as smoothing the design stage progress. The Technology Section is also responsible for preparation of all operation manuals by the technical writers as well as solving all deficiency reports arriving in engineering and which require a high level of quick-reaction solution. In addition, this section has the responsibility of all new product development activity. This involves laboratory studies, interfacing with outside vendors and consultants working on new products, field verification of prototypes and control for all standard drawing releases. Due to the versatility of these groups, we use our specialists for sales presentations, participation in field start-ups as well as supporting various technical aspects of proposal and estimating activities.

The Structural, Mechanical and Electrical Sections constitute the location of basic design activities which are no different than in any other type of engineering consulting office. Specific and somehow different, we might consider the special relation of these engineering personnel with fabricating units, field inspection and a more substantial involvement with design implementation activities.

A Standard Equipment Section exists to support engineering activities for equipment which requires a reduced amount of customization.

Our management computer programs provide also for a Section 7 and a Section 8, which are occasionally used for monitoring activities of engineering field offices, created from time to time to work on retrofit projects where substantial effort of in-plant engineering is required.

The composition of our engineering department requires approximately 7% Chief Discipline Engineers, 11% administration (secretarial, clerical and document control activities) and 82% drafters, designers and engineers. By function we find that our composition translates approximately as follows: 5% Project Engineering, 15% Technology, 30% Structural, 20% Mechanical, 20% Electrical and 10% Standard Equipment.

The flow of contractual activities is greatly facilitated by this type of organization (Figure 6).

Under certain circumstances such as special small projects, extremely tight schedules or very large projects, we contemplate using a task force approach. Under this approach the Project Engineer is totally in charge of a project with personnel removed as required from various engineering disciplines.

ECONOMICAL CONSIDERATIONS

The main objective of our engineering cost control is to properly forecast and execute high quality design work within estimated cost and schedules. Since engineering is participating in establishing material as well as engineering budgets, the problem of properly anticipating cost becomes a cycling feedback from proper monitoring of all components of engineering as well as project cost. Ultimately, the total cost of engineering per project is a simple equation: Total Cost = Cost Per Manhour x Number of Manhours.

We find it difficult to forecast the number of manhours required for projects with more than 10%-20% accuracy. This depends on many factors beyond our control such as drawing approval cycle, requirements for customer checking of drawings and calculations, quality of the shop drawings, performance of the personnel assigned to the project, etc. However, on the analysis of manhour cost components, there is a substantial amount of consistency.

The first consideration is to determine the engineering cost allocations components. Our economic calculations (Figure 7) monitor four categories. Work on contracts or jobs is our main consumer of manhours. Charges to other departments include pre-contract (estimating activities), support to service and construction, procurement, quality assurance, sales and marketing. In the engineering overhead we include the cost of training and education, jury duty, technical publications and presentations, review of deficiency reports, cost reduction programs, reliability committee activities and employee meetings. In addition, we also carry the cost of all our development and updating of engineering standard drawings and operating manuals. Field investigations for various disciplines, feasibility studies, mechanical studies and review of various gas flow problems which are not contract related and all new product development are carried as charges to others. Indirect costs cover strictly vacations, sick leave and holidays.

These costs are monitored monthly, quarterly and year-to-date on a fiscal year basis, which runs from October 1 to September 30.

Another approach to evaluation of engineering cost is through a detailed analysis of its various participating factors (Figure 8).

The base number for cost calculation takes into account the total number of manhours less all hours charged to indirect or overhead cost. Through this actual calculation on a monthly basis we experience a cost which varies approximately between $15-$20 per hour. One can readily observe the possible management improvements required.

We have found that attention should be given to managing cost of travel and clerical support which, properly coordinated, could affect a substantial reduction of total cost.

The cost of computer operations compared to total engineering cost has risen from 1.4% in 1977 to 2.5% in 1978. We foresee a continuous increase in this area. At present we are using both in-house written programs as well as programs commercially available which can eliminate unnecessary software development work.

The necessary feedback for maintaining economical visibility is obtained through daily input of timecards on a detailed code which reflects the everyday activity for every member of the engineering department, including all development work. Outside this monitoring program we have only clerical and supervision personnel at the chief discipline level. The additional required input is generated through our computerized scheduling system (Figure 9). The engineering schedule is written for all jobs per discipline and broken down into coded activities which we call bills of material.

At the end of each month (or weekly if required) we print the engineering manpower report (Figure 10). This proprietary program has many features. In essence it shows on every contract the performance against budgets and the performance estimates of every discipline listed by bills of material.

Other features of this program are the manpower forecast, which compares our existing levels with schedular commitments on all types of activities; schedule versus capacity, which reflects the total manhours available as resources compared to our present commitments; as well as a recapitulation by project and discipline of all manhours left to complete. These, as well as other features of this program, are required in order to generate the manpower level requirements necessary to meet schedular commitments for potential sales awards.

It has become acutely necessary to develop tools, based on which engineering management can properly forecast estimated manhour requirements as well as the possible milestone of completion, considering economically adequate manpower levels.

In order to enhance this capability, engineering, contract administration, sales and marketing review on a monthly basis all our outstanding proposals and develop the strategy required to maintain utilization of engineering resources at adequate levels. Such controls and visibility would lend themselves very easily for a cost-plus type of work, which we seldom perform at present. Organizations such as ours, I believe, would benefit from such type engineering contracts but the primary beneficiary would be the customer, who could control or correlate to a larger extent the degree of design requirements to engineering, materials and construction costs.

At present our engineering costs and sales are predicated mostly on lump sum basis. We are seldom profitable in this area. The cost of customized engineering precipitator and baghouse systems is relatively high. Without going into detail, it appears that our costs are at present in the range of 3% to 5% of material cost for precipitator systems, and 6% to 10% of material cost for baghouse systems. This includes the design of all support systems, loading diagrams, access facilities, flue work, electrical single line diagrams, all structural, mechanical and electrical engineering drawings, control and instrumentation, expansion joints, etc. On the main casing for precipitators, as well as baghouses, this cost includes the cost of shop fabrication drawings as well. Close cost monitoring is imperative for the engineering manager who is accountable for the cost of his operation.

MANAGEMENT OF DEVELOPMENT WORK

One of the most difficult jobs from a management viewpoint is the coordination of technical and financial problems related to development work.

We have found it beneficial to divide the responsibility for technical development work between our advanced technology and engineering departments. The criteria on which basis the work is assigned to either department are related to the scope of the respective project.

If we deal with new concepts or processes such as in the area of flue gas desulfurization, new chemical concepts or implementation of long range projects related to other agencies or institutions outside our organization, the projects fall within the jurisdiction of advanced technology. The engineering department is charged with managing new development projects which directly affect present state-of-the-art equipment such as transformer/rectifier rating studies, advanced type of voltage or rapping controllers, new types of high voltage electrodes, rapping acceleration response studies, testing and development of various proprietary equipment such as new expansion joints, model flow studies and others (see Figures 11 through 22).

We found this type of separation beneficial for two important reasons. First is that the manpower resources of the engineering department become more flexible to manage in terms of responding to urgent estimating or contract work demands or shifting into development work. Second, and more importantly, is the fact that we found that personnel close to our daily engineering problems has a good grasp for the need of pragmatic approaches to development projects. Using the engineering personnel in research and development type activity increases the creativity, level of interest, challenges and professional stature of design engineers.

Scheduling and financial monitoring of development work is a real challenge in many companies, particularly in organizations which have to mitigate competitive contractual demands with research and development work.

We have found it useful to have monthly reviews of all our development work progress. Milestones are established where decisions relating to continuation, branching in other directions or stopping work in various areas are regularly taken.

Each development engineer is reporting monthly on technical progress and our engineering administration monitors all cost associated. A summary of these reports gives management a good picture of all funding and allows at times the transfer of allocation from one area to another. These monthly reports (Figure 23) are submitted to higher level of management, which in our organization attributes a great deal of attention to research and development and product improvement work.

TRENDS AND CONCLUSIONS

In the environment prevalent today in our industry, dominated by substantial work in pre-engineering for proposals and strong competition for all new work, we have found many useful tools for engineering management.

The "Engineering Trends" report (Figure 24) monitors on a monthly basis our performance versus our forecast and gives us at a glance a summary of all other reporting systems.

We are closely monitoring what we call the "concentration factor." This gives us a measure of efficiency as well as the various unanticipated changes which are required when interfacing with our customers and their consultants. Monitoring our costs on a permanent basis gives us a valid basis for negotiating future contracts.

Another important tool is the manpower visibility report (Figure 25) which receives from the engineering manhour computerized report the status of all our contractual work and superimposes all commitments made to our customers for future work. With the aid of this tool we can respond to sales inquiries on a calendar basis for all proposals made to our customer on a solid, realistic base.

We believe that the last decade has changed the level of sophistication in the engineering work of our industry. Computerized techniques have been brought into our designs and drafting procedures. A new influx of talented engineers has joined the ranks of air pollution control system companies. Most of our projects have strict and well-written specifications requiring custom engineering of every major project. The cost of this effort has to be closely monitored.

New engineering optimization techniques which are presently developed should be brought into our industry on a larger scale. Computer graphics in all disciplines is coming rapidly into existence. The advent of computerized graphics will substantially contribute in the coming years not only to a substantial reduction of engineering cost but more importantly will allow evaluation of more design alternatives. This will directly contribute to better economical optimizations of our precipitator and baghouse systems.

Engineers and their employers are more aware of OSHA requirements as well as the legal liability involved in design of major projects. There is a growing concern toward safety, quality and reliability of our designs. We cannot afford failures and the best preventative measure is high quality engineering.

The successful completion of a baghouse or precipitator system project is largely predetermined by a judicious selection in sizing and arrangement. The forecasted trend indicates greater efforts in this area: the utilization of more complex, computerized models as well as a return to pilot plants of various sizes to adjust analytical coefficients required for our calculations. Opacity requirements and a maze of EPA regulations, some better understood than others, will demand a rapid technological increase in the state-of-the-art of our industry.

Flue gas desulfurization is the important issue of the hour. Wet and dry processes are developed, tested and currently installed on several sites. Existing possibilities for utilization of the removed particulate are already into advanced stages of testing. Gas cleaning, using technology associated with high pressure and temperatures, is presently developed and discussed in various forums. All these developments, as well as design of large installations at medium-elevated temperatures will require development of new construction materials and techniques. Some of this material is available as a fallout of aerospace developments but is still in a high price domain. Others wait to be marketed at more reasonable costs such as new alloy steels to bridge the gap between low alloy and chrom-moly steels.

We are increasing our efforts in studying results of our systems performance. This data will soon be used as feedback in new controllers using on-site microprocessors.

An increased activity in the economical evaluations of various alternatives for pollution control such as baghouses, precipitators on cold- and hot-side, with or without gas conditioning, and various types of scrubbers has been generated by the increasing demand of high efficiencies coupled with increased use of low sulfur western coals.

Competitive demands of the precipitator market and stricter specifications will continue to increase the establishing of new standards as they relate to wide collecting curtain spacing, various types of rigid frames and mast electrodes as well as flail hammer rapping.

Two-stage precipitation with separate units for charging and collecting are revived after being shelved for many years. Intensive testing will determine if such systems will be less costly and enhance precipitator efficiencies.

Above all, engineering management is people management. Engineers are at present in high demand and the trend will probably continue in the coming years. To properly manage, one has to understand the needs of capable technical people in terms of professional challenge and motivation. Elements of applied psychology are permeating all levels of management. This trend will probably benefit our profession in a substantial manner. By providing the proper incentives and by properly recruiting and training the new generation of engineers and scientists, we will insure a continuous progress of the air pollution control industry in the decades ahead.

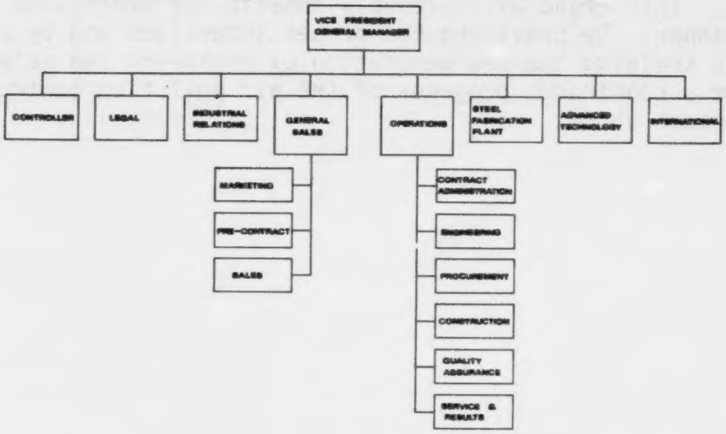
VICE PRESIDENT GENERAL MANAGER
CONTROLLER
LEGAL
INDUSTRIAL RELATIONS
GENERAL SALES
OPERATIONS
STEEL FABRICATION PLANT
ADVANCED TECHNOLOGY
INTERNATIONAL
MARKETING
PRE-CONTRACT
SALES
CONTRACT ADMINISTRATION
ENGINEERING
PROCUREMENT
CONSTRUCTION
QUALITY ASSURANCE
SERVICE & RESULTS

Figure 1. Western Precipitation Organizational Chart

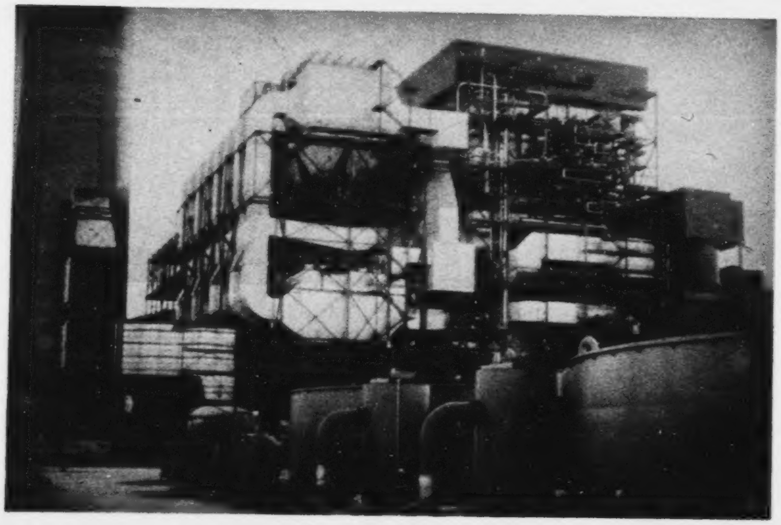

Figure 2. Salt River Project, Navajo Station (Bechtel Power), Units 1, 2 and 3

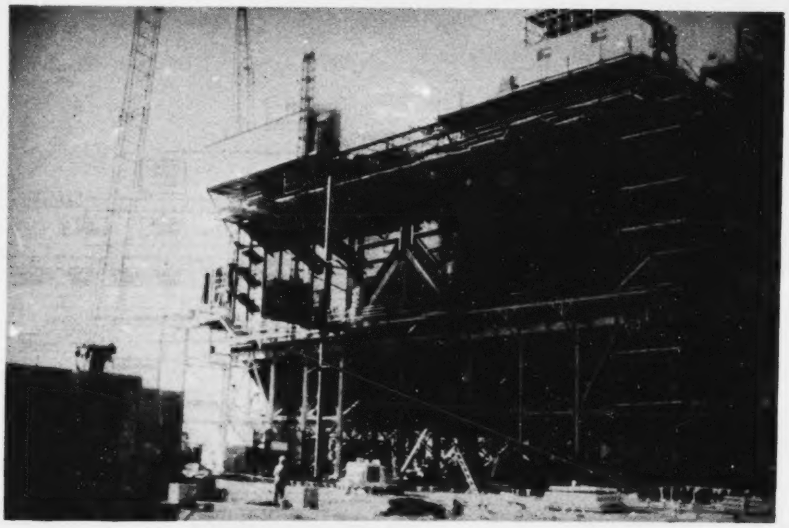

Figure 3. Salt River Project, Navajo Station (Bechtel Power), Units 1 and 2

Figure 4. Minnesota Power & Light Co. (Black & Veatch) Clay Boswell Plant, Units 1 and 2 - Erection Details

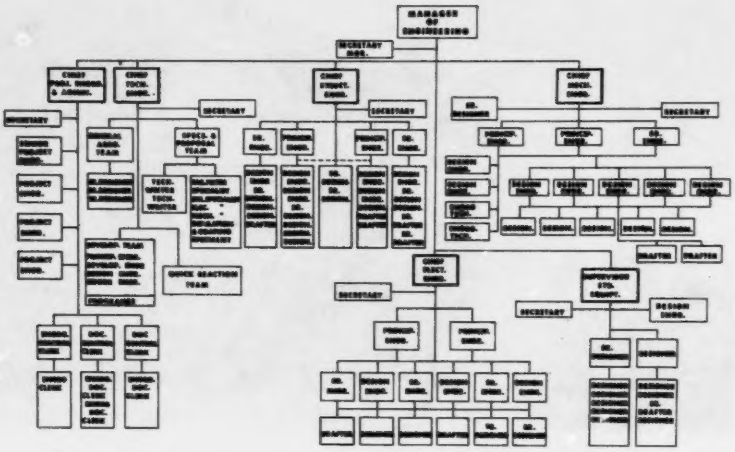
MANAGER OF ENGINEERING
SECRETARY
SECRETARY
SECRETARY
SECRETARY
SECRETARY
SECRETARY
QUICK REACTION TEAM
DESIGN ENGR.
DRAFTER
DRAFTER

Figure 5. Engineering Department Organizational Chart

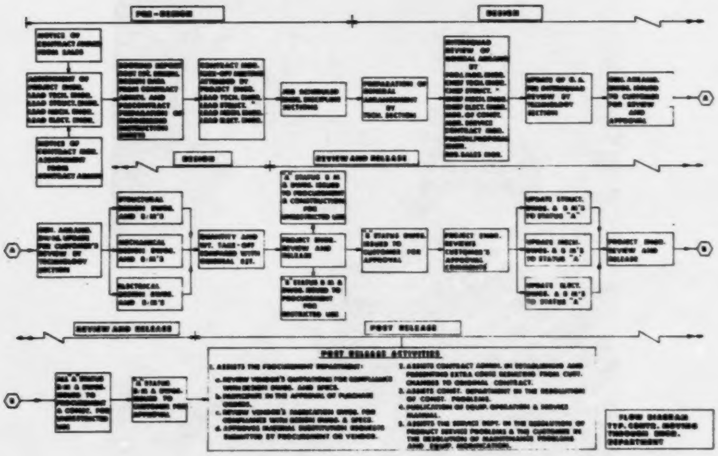
PRE-DESIGN
DESIGN
DESIGN
REVIEW AND RELEASE
REVIEW AND RELEASE
POST RELEASE
POST RELEASE ACTIVITIES
A
A
B
B

Figure 6. Flow Diagram - Engineering Department

	1977 %	1978 Year-To-Date %	1978 First Quarter %	1978 Second Quarter %	1978 Third Quarter %	1978 Fourth Quarter %
HOURS						
Charges to Others	11.1	X	12.64	17.47		
Engineering Overhead	16.5	X	3.78	6.86		
Indirect (Vacations, Sick Lv. & Holidays)	10.4	X	15.22	9.03		
Job Charges	53.1	X	68.36	66.64		
Total	100.0	100.00	100.00	100.00		
% of Time Available for Production	89.0	X	84.78	90.97		
% of Time Spent on Production	69.0	X	80.63	73.25		

ENGINEERING COST COMPONENTS

Figure 7. Engineering Cost Components

	1977 $/%	1978 Year-To-Date $/%	1978 First Quarter $/%	1978 Second Quarter $/%	1978 Third Quarter $/%	1978 Fourth Quarter $/%
COSTS						
111 Supervision	9.2	X	7.9	8.3		
117 Clerical	4.8	X	4.8	5.1		
118 Technical*	60.0	X	59.8	62.6		
491 Outside Engrg.**		X	4.3	1.0		
162 Overtime	.8	X	1.1	.4		
229 Fringe Benefits	18.3	X	15.8	14.1		
360 Office Supplies	.3	X	.5	.4		
4xx Other Services	.7	X	.3	.8		
476 E.D.P. Rentals	1.0	X	.2	-		
531 Travel	3.4	X	1.4	4.1		
5xx Other Expenses	1.1	X	1.9	.6		
958 Data Processing	.4	X	2.0	2.6		
Total	100.0	100.0	100.0	100.0		

* Design Engineers and Drafters (Salary Cost)
**JobShoppers

ENGINEERING COST DETAIL

Figure 8. Engineering Cost Details

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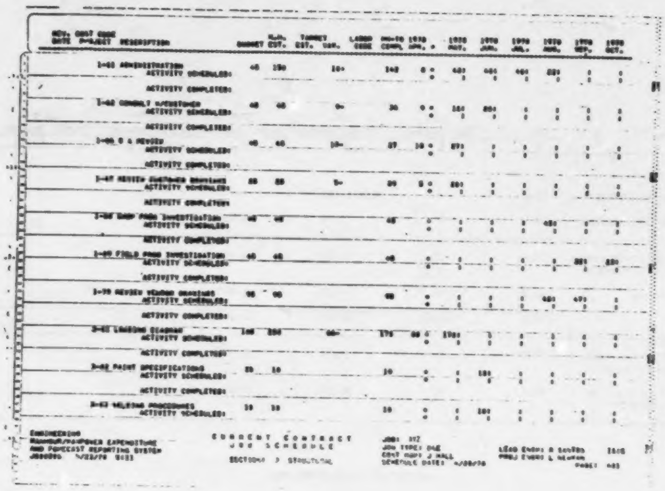


Figure 9. Engineering Schedule Example

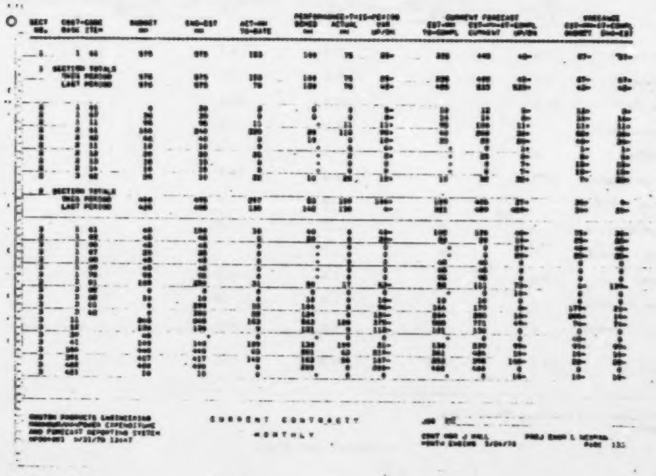


Figure 10. Engineering Manpower Report Example

Figure 11. Electrical Laboratory Studies

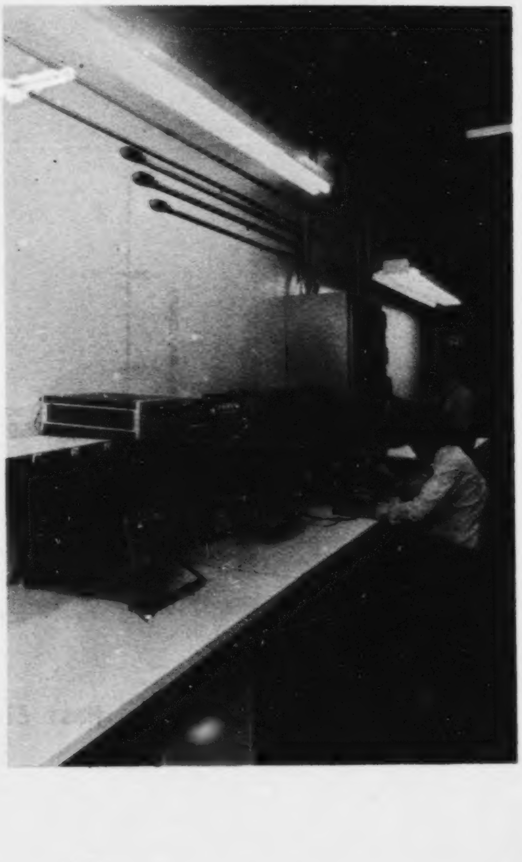


Figure 12. High Voltage Laboratory

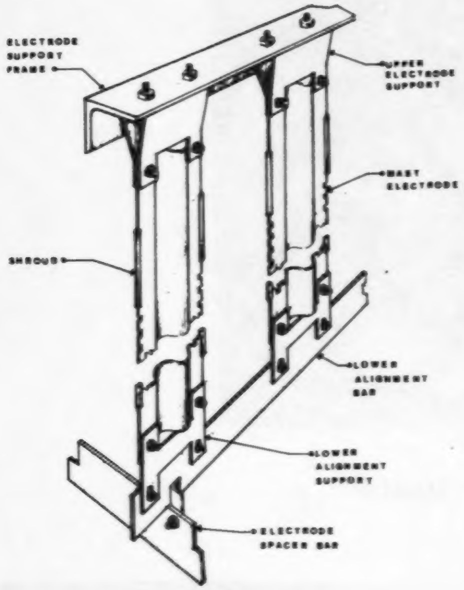

ELECTRODE SUPPORT FRAME
UPPER ELECTRODE SUPPORT
MAST ELECTRODE
SHROUD
LOWER ALIGNMENT BAR
LOWER ALIGNMENT SUPPORT
ELECTRODE SPACER BAR

Figure 13. Mast Electrode Concept

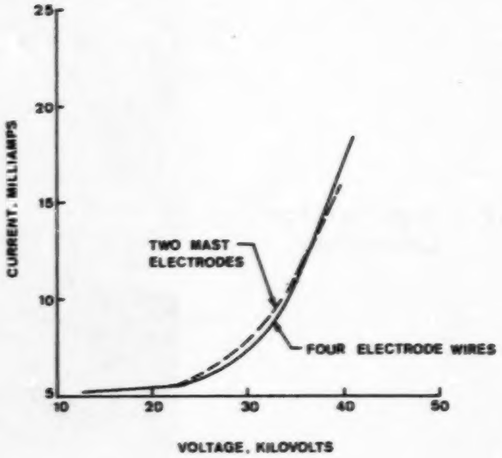


Figure 14. Mast Electrode vs. Wires - V-I Curve

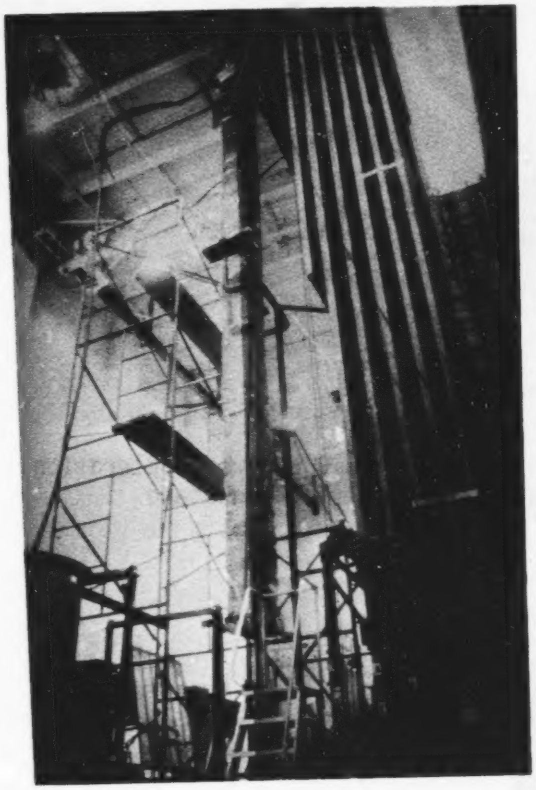


Figure 15. Mast Electrode Heat Warpage Testing

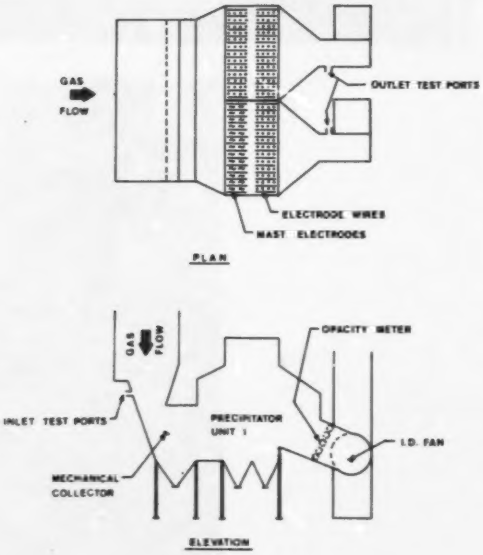

GAS
FLOW
OUTLET TEST PORTS
ELECTRODE WIRES
MAST ELECTRODES
PLAN
GAS FLOW
OPACITY METER
INLET TEST PORTS
PRECIPITATOR UNIT 1
I.D. FAN
MECHANICAL COLLECTOR
ELEVATION

Figure 16. Mast Electrode Field Experiment

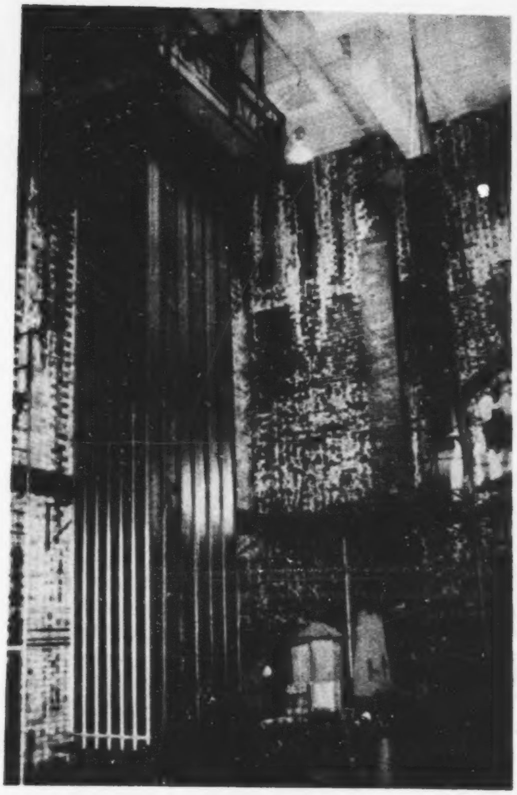


Figure 17. Curtains Acceleration Testing Stand

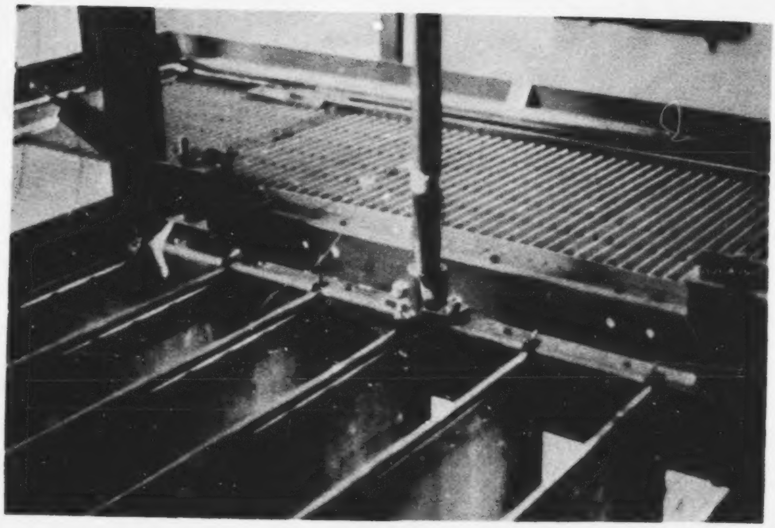


Figure 18. Edge Rapping Testing

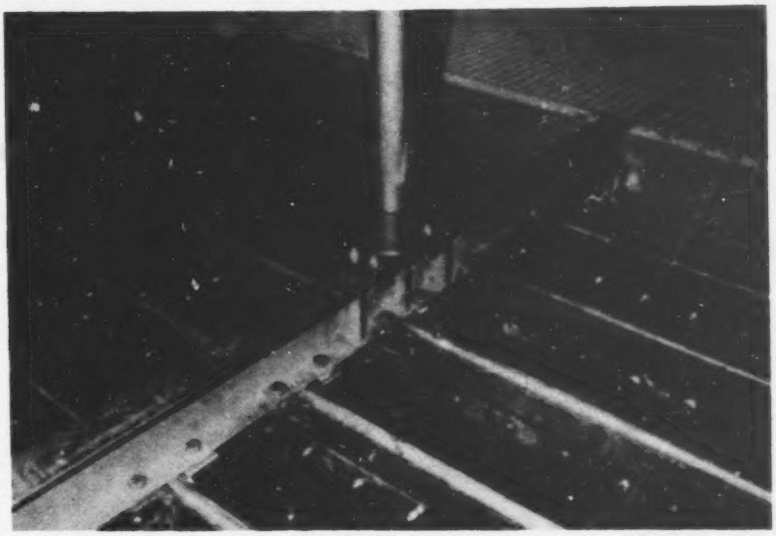


Figure 19. Center Rapping Testing

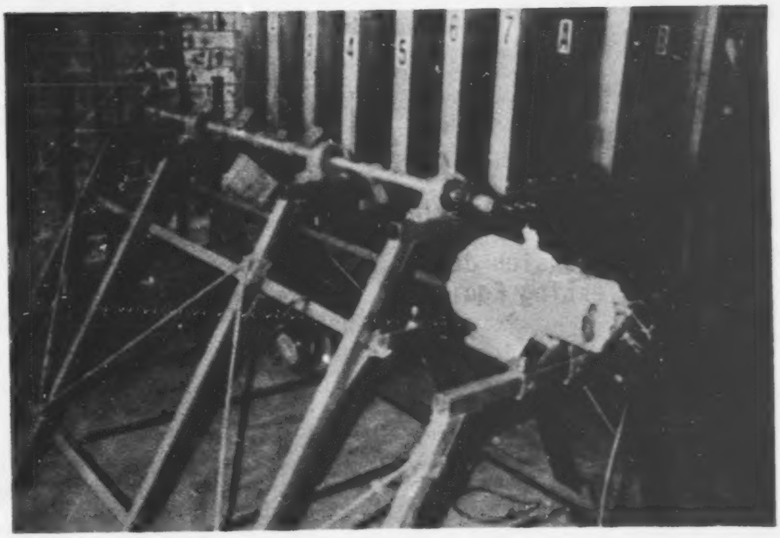


Figure 20. Flail Hammer Testing

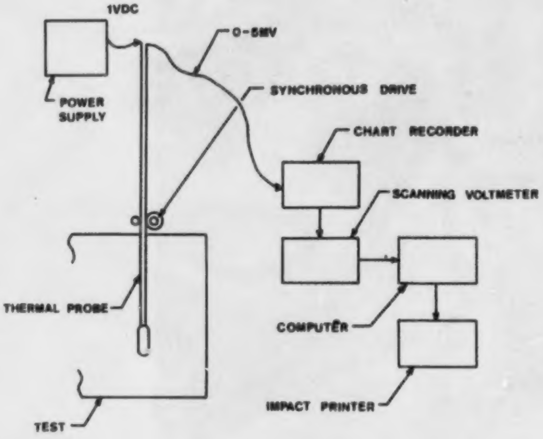

1VDC
0-5MV
POWER SUPPLY
SYNCHRONOUS DRIVE
CHART RECORDER
SCANNING VOLTMETER
THERMAL PROBE
COMPUTER
IMPACT PRINTER
TEST

Figure 21. Acceleration Testing Instrumentation

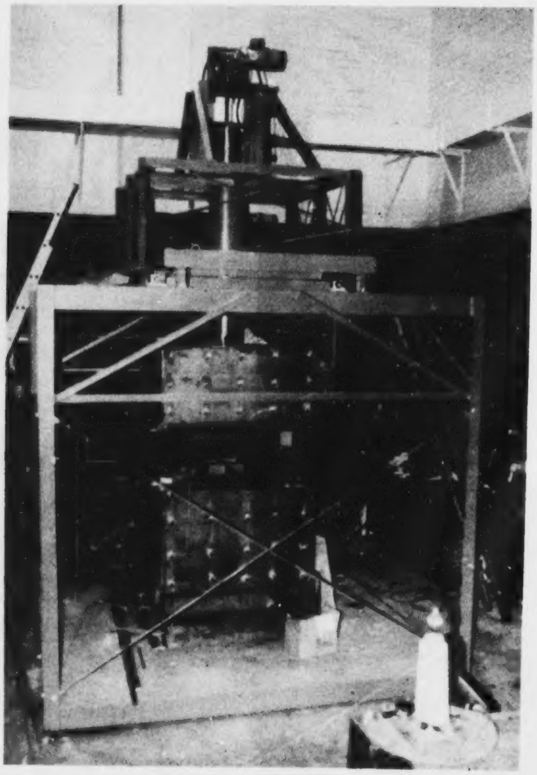
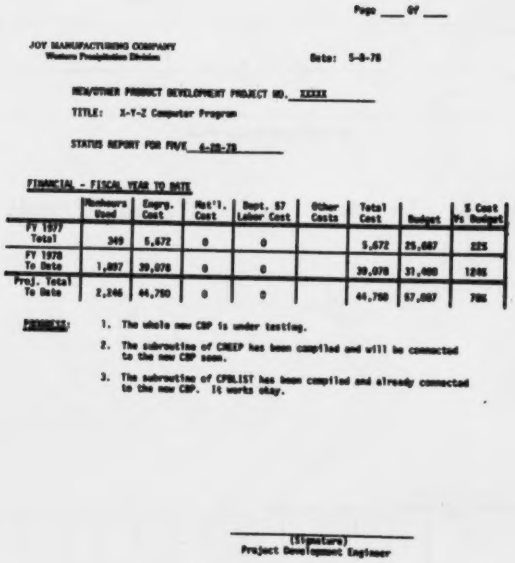


Figure 22. Expansion Joint Testing Equipment



Page ___ Of ___

JOY MANUFACTURING COMPANY
Western Precipitation Division

Date: 5-8-78

NEW/OTHER PRODUCT DEVELOPMENT PROJECT NO. XXXXX

TITLE: X-Y-Z Computer Program

STATUS REPORT FOR MO/E 4-28-78

FINANCIAL - FISCAL YEAR TO DATE

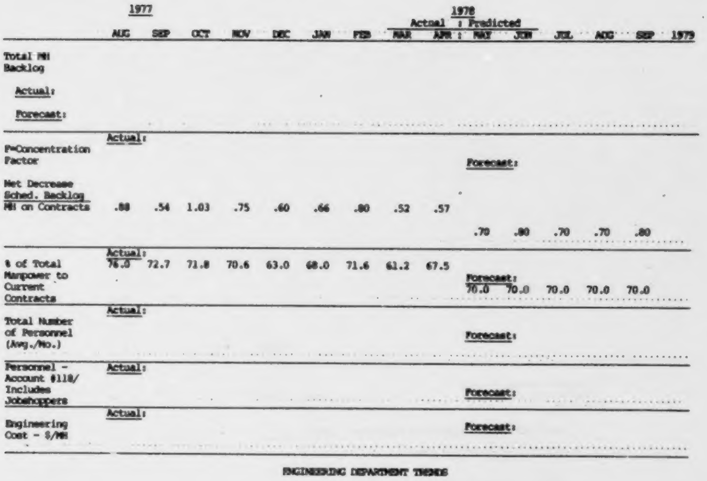
	Manhours Used	Engrg. Cost	Mat'l. Cost	Dept. 57 Labor Cost	Other Costs	Total Cost	Budget	% Cost Vs Budget
FY 1977 Total	349	5,672	0	0		5,672	26,087	22%
FY 1978 To Date	1,897	39,078	0	0		39,078	31,000	126%
Proj. Total To Date	2,246	44,750	0	0		44,750	57,087	78%

PROGRESS:

1. The whole new CBP is under testing.
2. The subroutine of CREEP has been compiled and will be connected to the new CBP soon.
3. The subroutine of CPBLIST has been compiled and already connected to the new CBP. It works okay.

(Signature)
Project Development Engineer

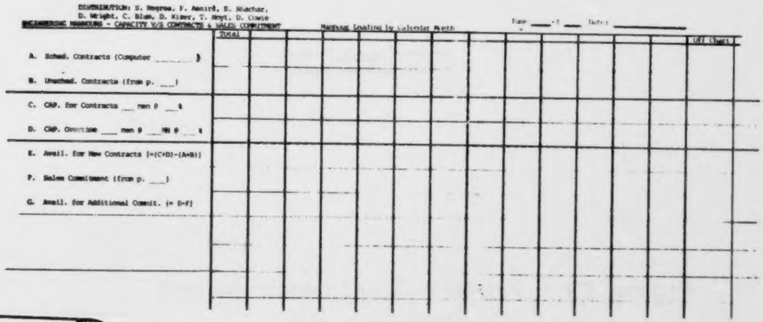
Figure 23. Project Development Report Example



	1977					1978									
								Actual		: Predicted					
	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	: MAY	JUN	JUL	AUG	SEP	1979
Total MH Backlog															
Actual:															
Forecast:															
F=Concentration Factor	Actual:									Forecast:					
Net Decrease Sched. Backlog MH on Contracts	.88	.54	1.03	.75	.60	.66	.80	.52	.57	.70	.80	.70	.70	.80	
% of Total Manpower to Current Contracts	Actual: 76.0	72.7	71.8	70.6	63.0	68.0	71.6	61.2	67.5	Forecast: 70.0	70.0	70.0	70.0	70.0	
Total Number of Personnel (Avg./Mo.)	Actual:									Forecast:					
Personnel - Account #118/ Includes Jobshoppers	Actual:									Forecast:					
Engineering Cost - $/MH	Actual:									Forecast:					

ENGINEERING DEPARTMENT TRENDS

Figure 24. Engineering Department Trends



DISTRIBUTION: S. Negrea, F. Amsird, S. Shachar, D. Wright, C. Blum, D. Kiser, T. Hoyt, D. Cowie

ENGINEERING MANHOURS - CAPACITY V/S CONTRACTS & SALES COMMITMENT

Manhour Loading by Calendar Month

Page ___ of ___ Date: ___________

	Total														Off Chart
A. Sched. Contracts (Computer ________)															
B. Unsched. Contracts (from p. ___)															
C. CAP. for Contracts ___ men @ ___ %															
D. CAP. Overtime ___ men @ ___ MH @ ___ %															
E. Avail. for New Contracts [=(C+D)-(A+B)]															
F. Sales Commitment (from p. ___)															
G. Avail. for Additional Commit. (= E-F)															

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Figure 25. Manpower Visibility Report

ABSTRACT

Control of Particulates from Combustion

J. H. Abbott and D C. Drehmel
Environmental Protection Agency
Research Triangle Park, N.C.

The Environmental Protection Agency's Industrial Environmental Research Laboratory in North Carolina (IERL-RTP) has responsibility under the Clean Air Act of 1970 for the development and demonstration of control technology for air pollutants emitted from stationary sources. One of the pollutants among the six frequently referred to as criteria pollutants is particulate matter. It is the responsibility of the Particulate Technology Branch (PATB) of IERL-RTP to develop and demonstrate, on a pilot scale, control technology that is generally applicable to particulate and fine particulate matter emitted from all stationary sources, including combustion sources.

For the past five years PATB has been engaged in a program aimed at determining the limitations of conventional particulate control devices and at defining a research and development effort that will eventually produce the needed technology for the control of fine particulates. In addition IERL-RTP has established a program to develop control technology for fine particulates.

From the data developed by PATB it can be concluded that adequate control of emitted submicron particulate matter is presently possible, but not broadly applicable to a wide variety of sources.

Highly efficient electrostatic precipitators installed on sources whose dust properties are such that they lend themselves to electrostatic collection can currently be effective in controlling fine particles. Additional research and development is needed, however, to improve the performance of precipitators on particulate in the size range of 0.1 to 1 mircons. This size range is quite important since it is the most optically active and causes atmospheric haze and thus visibility problems. Techniques that either enhance charging or selectively charge fine particles are currently being developed by Industrial Environmental Research Laboratory.

Conventional scrubbers are not very efficient collectors of fine particles. Current research and development efforts in improve scrubbers are directed toward more efficient utilization of the energy applied to a scrubber system, and toward taking increased advantages of condensation and other physical phenomena that affect, to some degree, the performance of all scrubbers.

Fabric filters, insofar as current test data show, are quite effective collectors of fine particles. Their use is currently limited by the physical properties of the filter media and by the large size of the required container. Most mechanically durable, as well as chemical and heat resistant filters, are needed. In addition, filters must be developed that can be used as air-to-cloth ratios 10 to 100 times greater than is the current practice. An increase in the allowable level of this parameter will result in a direct reduction in container size.

CONTROL OF PARTICULATES FROM COMBUSTION

I. NATURE OF THE PROBLEM

Millions of tons of particulates are emitted into the atmosphere every year. In the year 1976, the total nationwide emission estimates were 13.4 million metric tons of which stationary fuel combustion sources contributed 4.6 million metric tons.[1] The majority of the stationary fuel combustion emissions were from electric utilities and were estimated to be 3.2 million metric tons. As of 1975, the total electric power generation for fossil fuel plants of 25 MW or greater was 347,720 MW.[2] Of this total 60 percent was generated with coal; 19%, oil; 21% gas. Between now and 1990, combustion of gas and oil is expected to remain relatively constant but the combustion of coal could almost double.[3] Hence, particulates from combustion are not only a major source of total particulates now but also a continuing problem for the future.

The properties of combustion particulates or fly ash are under intensive study and are known to be highly variable. For example, the particle size distribution can include a small or large fraction in the respirable range. Tests performed by EPA's Industrial Environmental Research Laboratory at Research Triangle Park (IERL/RTP) show that the mass median diameter can range from 9 to 50 μm[4,5,6] for fly ash from coal-fired power plants (see Figure 1). Because of the large size distribution of fly ash (geometric deviations of 3.3 - 5.0), even a mass median diameter as large as 50 μm implies a significant emission for particle sizes less than 3 μm. It has been estimated that coal-fired power plants release 0.6 million tons/year in the 1-3 μm range; 0.2 in the 0.5-1.0 μm range; and 0.1 in the 0.1-0.5 μm range.[7] Coal-fired industrial boilers and oil-fired power plants and industrial boilers also have significant emissions in the 1-3 μm range of 0.1 and 0.2 million tons/year, respectively.[7]

Other properties of interest for fly ash are the physical state and composition. With respect to physical state, fractions of fly ash have been characterized according to relative abundance of 12 morphological classes.[8] The most abundant forms were the non-opaque solid spheres and non-opaque cenospheres. Other important types were the rounded, vesicular, non-opaque and the amorphous, non-opaque. Variation in physical state with particle size has been noted with predominance of the opaque solid spheres in the submicron range. Morphology can be related to composition. Coal components give the opaque amorphous particles; iron with silicates give opaque spheres; and silicates give non-opaque particles.

Trace elements are to be found in fly ash and in some cases represent a significant fraction of the total emission of that element.[9] Annual emissions in coal-fired power plant fly ash for arsenic are 493 tons; beryllium, 99 tons; lead, 706 tons; and mercury, 173 tons. Given the above trace elements, the toxic and carcinogenic effects of fly ash are suspected. Currently, biological testing has shown that both organic and inorganic mutagens are present in coal fly ash.[8] Further testing is needed to determine if these mutagens are also carcinogenic.

II. APPLICABLE CONTROL TECHNIQUES AND CAPABILITIES

For conventional combustion sources, the control options available are electrostatic precipitators (ESP's), fabric filters, scrubbers, cyclones, and combinations of devices such as an ESP followed by a scrubber. With respect to ESP applicability, IERL/RTP tested them on coal-fired utility boilers and concluded that a high level of control was possible even for very small particles (see Table 1 and Figure 2). It had been believed that the removal efficiency of an ESP would drop rapidly for particles below about 2 μm in size. This is the size at which the main particle charging mechanism called "field charging" begins to become ineffective. These results indicated that, even in the submicron range, significant collection, and thus particle charging, occurs. The charging process, which comes into significance on these very small particles, is termed "diffusion charging." ESP's are widely used today on coal-fired utility boilers. They cost more to install than scrubbers or fabric filters, but they're less expensive to operate. The main drawback to current ESP's is their inability to effectively and economically trap certain types of fine particles--such as fly ash from low-sulfur coal. These are particles with high electrical resistivity, which makes them difficult to collect electrostatically without incurring very high initial capital costs.

Wet scrubbers have been used as particulate collection devices since the early 1920's. Although they're inexpensive to install compared to large baghouses or ESP's, scrubbers are costly to operate. They require large amounts of water and electricity, and create a sludge.

IERL/RTP's Particulate Technology Branch has tested scrubbers of conventional design on a variety of particulate sources. In general, the efficiency of a scrubber drops off rather rapidly as the particle size decreases (see Figure 3). It can also be said that the efficiency is directly related to the energy consumed by the scrubber. Table 2 shows these results in terms of the cut diameter and in terms of the diameter at which the efficiency falls below 80%.

The Particulate Technology Branch (PATB) has also tested collection efficiency down to 0.08 μm and found that scrubbers have an analogous minimum in their collection curves as ESP's have. The efficiency of a TCA scrubber on a coal-fired power plant decreased to 30% collection at 0.4 μm and then increased back to 97% at 0.08 μm (see Figure 4). As with the ESP minimum, two mechanisms are involved. For coarse particles, collection is by impaction; for very fine particles, by diffusion. Since 0.4 μm diameter particles have neither a high diffusivity nor a large inertial mass for impaction, they are the most difficult to collect.

Fabric filters or baghouses have the highest efficiencies in collecting particulate emissions and are the most effective in controlling fine particulates. The Particulate Technology Branch has tested two installations on utility boilers and one on an industrial boiler.[10,11] The results of these tests show greater than 95% collection at all sources in all size ranges tested from 0.1 to 4 μm (see Figure 5). Results for each site are:

1. At the Sunbury pulverized coal-fired power plant with glass/Teflon bags and an air-to-cloth ratio of 2, the overall mass removal efficiency was 99.9%. The outlet loading was 0.0039 grams/m^3 (0.0017 g/dscf). The efficiency was 99% at 0.1 μm, near 98% at 0.5 μm, and above 99% at 1.0 μm.

2. At the Nucla stoker coal-fired power plant with graphited glass bags and an air-to-cloth ratio of 3, the overall mass removal efficiency was 99.8%. The outlet loading was 0.0071 g/m^3 (0.0031 gr/dscf). The efficiency was 99% at 0.1 μm, 99% at 0.5 μm, and greater than 99% for 1.0 μm.

3. At the Kerr Industries stoker coal-fired industrial boiler with Nomex bags and an air-to-cloth ratio of 3, the overall efficiency was 99.2%. The outlet loading was 0.0046 g/m^3 (0.002 gr/dscf). The efficiency was almost 99% at 0.3 μm, about 95% at 0.6 μm, and back up to greater than 98% at 2.0 μm.

Among the least expensive particulate collectors are cyclones. These are widely used to clean up industrial operations like grinding and polishing metals, crushing stone and gravel, and woodworking. Though cyclones are very efficient for large particles, they are only about 40% efficient for fine particles. The efficiency of cyclones can be improved by increasing the velocity of the airflow--but only at the cost of substantially more energy. As a result, cyclones work best on sources that do not emit great numbers of fine particles such as combustion sources.

Recently, combinations of control devices have become of interest. The use of scrubbers for SO_2 control combined with other devices for particulate control offers some potential advantages. If the particulate control device treats the flue gas before the scrubber, the scrubber circuit will be relatively free of fly ash allowing easier treatment or re-use of scrubber products. If one of the control devices must be taken out of service for maintenance the remaining control device will continue to collect the primary pollutant for which it was designed and may also provide some collection for the other pollutant. If the combination of interest is an ESP followed by an SO_2 scrubber, both the control devices provide particulate collection and the ESP may be designed smaller than one not followed by the scrubber. This last conclusion resulted from a PATB in-house study using pilot scale equipment and computer models which produced the results shown in Figures 6 and 7. In Figure 6 are the penetration curves for each control device by itself. As noted previously, the efficiency of the scrubber decreases rapidly with decreasing particle size and that of the ESP decreases more slowly to a minimum around 0.5 μm. Comparing the 95% efficient ESP and the scrubber with a 25 cm pressure drop, shows that the scrubber is far more efficient above 0.8 μm and the ESP far more efficient below 0.8 μm. In combination they add to each other's capability with the result shown in Figure 7. To achieve this result with a scrubber alone, the pressure drop would have to be increased greatly to collect the very fine particles. Similarly, with an ESP alone, the specific collector area (SCA) would have to be increased greatly to collect large particles as efficiently as the ESP/scrubber combination. Working together, the ESP and scrubber can provide collection capabilities equal to more expensive single devices because of the different ways ESP's and scrubbers collect different particle sizes.

For advanced power cycles, control options include granular beds, ceramic filters, dry scrubbers, and high temperature/pressure ESP's. These devices must be applied to the specialized requirements of coal gasification, magnetohydrodynamics (MHD), or fluid bed combustion (FBC). In coal gasification, coal is converted to synthetic gas by burning under carefully controlled conditions at high temperature and pressure--temperatures as high as 1830°C at 1 atmosphere and pressures up to 100 atmospheres at 930°C. Much of the energy in the coal is retained by the synthetic gas to be burned in gas turbines, boilers, furnaces, kilns, or heaters. As supplies of natural gas become less abundant, it is proposed to use synthetic gas produced by coal conversion in pipelines to industries and homes eliminating the need to replace gas-burning equipment now in use.

Another important coal conversion process is pressurized FBC. Here, coal is burned under pressure in a bed of limestone or similar material resulting in 820°C combustion gases to be cleaned. The sulfur in the coal is removed by the limestone in the bed. The combustor generates both steam for electric power or industrial uses, and hot pressurized gases, which can be used to drive gas turbines. Typical gas parameters and particulate characteristics of gasifier and FBC streams are shown in Table 3.

Since these processes are at high pressure, the control device must be contained in a pressure vessel and hence it is economically imperative to keep the control device small. Since operating temperatures for the control device are above 820°C, ceramic materials must be used as collection media. Granular beds and dry scrubbers use discrete ceramic particles as collection sites. In a granular bed, the ceramic particles are fixed or moving with the particulate laden gas passing through the bed. Collection is by impaction, interception, and diffusion. In a dry scrubber, the ceramic particles fall through the particulate-laden gas which can be accelerated as in a venturi scrubber in order to maximize impaction collection. The ceramic filter can be either a ceramic membrane barrier or a ceramic baghouse. The high temperature/pressure ESP is likely to be similar to conventional low temperature wire-and-pipe designs.

III. REGULATORY MANDATES FOR PARTICULATE R&D

Particulates are one of the six air pollutants thus far identified by the Environmental Protection Agency (EPA) as having "potential for widespread adverse effects on human health and welfare." Acting on the authority of Section 109 of the Clean Air Act, December 1970, EPA has set a primary National Ambient Air Quality Standard for total suspended particulates in air of 75 micrograms per cubic meter (annual average).

Within the same act, Section III, EPA was also given the authority to set standards of performance for new stationary sources. The Act as revised by the 1977 Amendments states that the standard should reflect "the degree of emission limitation achievable through the application of the best system of continuous emission reduction which (taking into account the cost of achieving such reduction and any nonair quality, health and environmental impact and energy requirements) the Administrator determines has been adequately demonstrated for that category of sources." For particulate emissions from utility boilers the current limit is 43 ng/J (0.1 lb/million Btu).[12] A revision in this standard is currently under consideration. Preliminary drafts suggest that the standard might be 13 ng/J (0.03 lb/million Btu). Another possible control standard which would apply to particulate from combustion sources is Section 112 of the 1970 Clean Air Act Amendments which deals with national emission standards for hazardous air pollutants. This standard would apply to an air pollutant which may cause an "increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness."

As part of the development and enforcement of air pollution standards, Section 103 of the 1970 Clean Air Act Amendments states that EPA will establish a national research and development program which will, among other activities, do the following:

1) Conduct and promote the acceleration of research, experiments, demonstrations, etc. relating to prevention and control of air pollution.

2) Conduct investigations and research and make surveys concerning specific problems of air pollution

3) Develop effective and practical processes, methods, and prototype devices for the prevention or control of air pollution.

IV. Future Problems in Particulate Control

In the next 15 years, it has been estimated that coal consumption will increase dramatically because of dwindling supplies of oil and natural gas. By 1990, total coal consumption is expected to be close to 1.3 billion tons of coal annually which is almost twice the current rate.

Much of the coal burned today is eastern coal mined in Pennsylvania, Illinois, West Virginia, and Kentucky. However, since the early 1960's the use of western coal has expanded dramatically partly because of increased western energy needs and because of stricter SO_2 emission control requirements. Some of the low sulfur western coal is being shipped to eastern plants to avoid the need for flue gas desulfurization. With the enactment of the Clean Air Amendments of 1977, SO_2 emissions from new coal combustion sources must be reduced by a constant percentage whether western or eastern coals are fired. This will make it more difficult to comply with future Federal new source performance standards by firing low sulfur western coal without flue gas treatment. Consequently, expanded use of low sulfur western coal to meet SO_2 control regulations will be tempered. In spite of this mitigating factor it is expected that there will be a substantial increase in the use of western low sulfur coal.

Unfortunately, combustion of low sulfur coal produces fly ash with high electrical resistivity which is difficult to collect. Current solutions to the low sulfur coal particulate control problem include conditioning of the fly ash and changes in operating temperature of the ESP. Experience with conditioning agents can be summarized as mixed. They work sometimes and don't work other times. It is impossible to predict in advance which additive and how much of it will allow a given ESP to work. Probably the major unresolved problem with conditioning agents is their environmental impact. Even under best case conditions the use of conditioning agents changes the chemical composition of the particulate, and in some cases the gaseous emissions of a power plant. At least in some cases, this change in chemical composition may have adverse environmental impact.

If the operating temperature of the ESP is either lowered or raised, the resistivity of the fly ash is lowered and performance of the ESP enhanced. The typical application of this effect is to place the ESP before the air preheater instead of after the preheater in the power plant flue system. The precipitator is then on the hot side of the air preheater and operates at 400°C instead of 150°C. Although hot-side ESP's used by eastern utilities are satisfactory, hot-side ESP's used to control particulate emissions from power plants in the west burning low sulfur western coal perform worse than expected. The reason for the poor performance of these hot-side ESP's in the west is at present unknown.

In addition to problems with particulate from combustion in conventional systems, a new set of problems arise in advanced power cycles. Process constraints dictate control of particulate emissions at high temperature and pressure where materials problems are a major concern. The particulate matter under these conditions may be sticky or tend to agglomerate and blind the collection surface of the control device. Potential control devices are by and large only in an early state of development and high temperature cyclones will not meet current, much less revised, standards applied to conventional power systems.

Granular bed filters are being evaluated at the Exxon miniplant and at Air Pollution Technology, Inc. Difficulty in cleaning the bed has resulted in efficiencies falling from 92% to 46% during a 24-hour run at Exxon. Work at APT shows that good fine particle removal can only be obtained when using deep beds of fine granules. Unfortunately, because of entrainment of granules during bed cleaning, deep fine beds are the most difficult to clean.

Problems and limitations of high temperature and pressure control devices can be summarized as follows:

Device or Technology	Major Problems or Limitation	Can Meet 13 ng/J?
Granular beds	poor efficiency	no
Ceramic filters	difficult to clean	yes
Dry scrubbers	high pressure drop	yes
Ceramic bags	unknown bag life	yes
Electrostatic precipitators	unknown operation	unknown

Use of coal cleaning may also present some future problems in particulate control. Although the percent ash in the coal will be reduced, the removal of sulfur gives rise to a high resistivity fly ash as experienced with low sulfur western coals. Problems with high resistivity ash were noted above. Another potential problem is that combustion of cleaned coals will produce a very fine particulate emission which will be difficult to collect because of its size.

V. SIGNIFICANT DEVELOPMENTS

The EPA has completed work to determine the electrical conduction mechanisms in fly ash at high temperatures (390 C). Work in this area is being extended to low temperatures. An outcome of this work has been the demonstration of sodium as a potential conditioning agent to reduce fly ash resistivity. The EPA has evaluated and published reports on conditioning agents such as SO_3 and NH_3. Conditioning appears to be a possible solution to retrofit problems, but not for new installations. Conditioning will not be a solution if it causes adverse environmental effects. IERL/RTP will conduct further tests to assess the total impact of conditioning. One test has already been completed; preparation for others is currently in progress.

Specially designed charging or precharging sections are a possible means of improving the collection of fine high-resistivity particles. A fundamental study and limited pilot-plant work on particle charging was begun in FY-74. This work was continued through FY-76 and resulted in a laboratory demonstration of the feasibility of the concept. A pilot-scale demonstration was funded in FY-77.

A mathematical model for the design of ESP's was completed in FY-75. This model is in two forms: a design and selection manual for the plant engineer and a programmed computer version for the design engineer. The model predicts well the performance of ESP's down to particle sizes approaching 0.01 μm. Programs in FY-76 and -77 resulted in improvements in this model in the areas of defining the effects of gas distribution, rapping, and reentrainment.

The major thrust of EPA's scrubber program has been aimed at developing and demonstrating flux force/condensation (FF/C) scrubbers. In an FF/C scrubber, water vapor is condensed in the scrubber. When the water vapor condenses, additional forces and particle growth contribute to particle collection. When the water vapor or steam is "free," FF/C scrubbers are low energy users. However, when water vapor or steam has to be purchased, FF/C scrubbers require additional energy for efficient particle collection. Answers to questions of how much steam is needed and how much is free are major unknowns. Answers to both questions are likely to be source specific. Thus, pilot demonstrations on a variety of sources are necessary to provide required data. One pilot demonstration has been completed; a second is underway.

Overall efficiency of a scrubber system is determined by the efficiency of the scrubber and the efficiency of the entrainment separator. Recent field data indicate that in some cases inefficient entrainment separator operation is a major cause of poor fine particle collection by scrubbers. The EPA has recently completed a systems study of entrainment separators. In FY-76 the design of these separators was optimized for fine particle control. This design is now ready for demonstration.

Filtration work performed under IERL/RTP's PATB has been aimed at acquiring information for a two-fold use: incorporation into mathematical models; and addition to the empirical knowledge used by designers and operators for everyday operation. This work has included: studies of fiber property and fabric-type effects; evaluation of new fabrics; development of mathematical descriptions for specific parts of the filtration process; characterization of fabric filters in the field; investigation of electrostatic effects; support of a pilot (and now a demonstration) program to apply fabric filtration to industrial boilers at a several-fold increase over normal filtration velocity; studies of cleaning and energy consumption in bag filters; and a pilot program for control of municipal incinerators.

The fabric filter has recently taken on added importance as a control device for utility boilers burning low-sulfur coal, the fly ash of which is very difficult and expensive to control with ESP's. The EPA in FY-77 funded a demonstration test of a baghouse installed on a 350 MW boiler burning a low-sulfur coal.

Accomplishments of the fabric evaluation program included:

- Demonstration of superior filtration performance by spunbonded fabrics, compared to similar weights of woven fabrics of the same fiber. The laboratory evaluation justifies field evaluation of this fabric.
- Confirmation of the unique filtering action of one of the classes of polytetrafluoroethylene (PTFE) laminate fabrics. The fabric filtered fly ash very effectively especially for particle sizes in the respirable range (0.01 to 3 m).
- Identification of polyester as suitable for filtering cotton dust.
- Measurement of the performance of uncalendared needled felt fabrics in the pulse-jet unit, and measurement of the endurance of variously coated fibrous glass fabrics in the high temperature baghouse.

A fleet of mobile conventional collectors which can be easily transported from source to source and tested has been constructed and will be used in support of this program.

The fleet includes a mobile fabric filter, a mobile scrubber, and a mobile ESP unit. These highly versatile mobile units are being used to investigate the applicability of these control methods to the control of fine particulate emitted from a wide range of industrial sources. Relative capabilities and limitations of these control devices are being evaluated and documented. This information, supplemented by data from other IERL/RTP particulate programs, will permit selection by equipment users of collection systems that are technically and economically optimum for specific applications.

The mobile fabric filter unit has been operated on effluents from a brass and bronze foundry, a hot-mix asphalt plant, a coal-fired boiler, a lime kiln, and a pulp mill recovery boiler. It has also been used to determine the performance of a fabric filter on air emissions from a cyclone collector used on the St. Louis Refuse Processing Plant. The filter unit most recently was operated at a Southwest Public Service Company site to obtain preliminary data for an EPA-funded demonstration ot a fabric filter on a 350 MW boiler burning low-sulfur coal. The mobile wet scrubber unit has been operated on a coal-fired power plant, a lime kiln in a pulp and paper mill, and on a gray iron foundry. The mobile ESP is operating in the field for the first time, on an industrial boiler burning a mixture of coal and pelletized refuse. This was used at a field site to evaluate the effects of sodium conditioning on a low-sulfur western coal, and is currently being used on the hot side of the air preheater at a western power plant to help determine the reasons behind the failure of hot-side ESP's to perform as well as design would predict when used to control fly ash from western low sulfur coals.

In the high temperature/pressure particulate control area, bench scale work on ceramic filters and ceramic bags has shown that the media can survive operating conditions and provide high collection efficiencies (see Table 4). Results on dry scrubbers, like on aqueous scrubbers, have proven that they will require high pressure drops to achieve good fine particle control unless an analog to the charged droplet scrubber can be developed. The ESP tests have demonstrated stable corona; however, no efficiency data or projections are available yet.

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Table 1. RESULTS OF FIELD TESTS ON ELECTROSTATIC PRECIPITATORS

					Efficiencies, % Particle Diameter				
Source	Type ESP	SCA sq m/actual cu m/sec	Temperature, °C	Overall	2 micron	1 micron	0.5 micron	0.1 micron	Comments
Coal-Fired Boiler	Cold Side	54	150	99.6	98.9	97	95	98	Moderate sulfur coal
Coal-Fired Boiler	Cold Side	54	160	99.8	99.9	99.6	99	99	High sulfur coal; no impactor data
Coal-Fired Boiler	Cold Side	65	160	98.3	99	96	80	98	Low sulfur coal
Coal-Fired Boiler	Hot Side	85	375	99+	99.6	97	95	99.3	Tests completed; data not reported

Table 2. FINE PARTICLE CONTROL BY SCRUBBERS

Name	Pressure Drop, cm WC	Smallest Diameter Collected at Stated Efficiency, µm 80%	50%
Ducon	8	1.6	1.3
Wet Fiber	19	1.1	0.6
Chemico Venturi	25	0.9	0.7
UOP/TCA	30	0.7	0.35
Venturi Rod	273	0.5	0.3

Table 3. RANGES OF GAS STEAM AND PARTICULATE CHARACTERISTICS FOR ADVANCED ENERGY PROCESSES

	FBC	Gasifier
Temperature, °C	760-980	150-1,100
Pressure, atm	1-10	1-70
Mass Loading, g/Nm^3	0.09-4.8	18-230
Mass Median Diameter, μm	1.2-8	≤ to 300
Gas Composition (Major Components)	N_2, CO_2, O_2 H_2O, SO_2, NO, CO	H_2, CO, CO_2, N_2 H_2O, CH_4, H_2S

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	H_2O, SO_2, NO, CO	H_2O, CH_4, H_2S

Table 4. DEVELOPMENTS IN HIGH TEMPERATURE/PRESSURE PARTICULATE CONTROL

	Completed to Date	Measured Efficiency, %	Problems	Conclusions
Ceramic Filters	850 m^3/hr tests	93-100 at 820°C[13]	Difficult to clean sticky particles	Requires in-house tests on cleaning of more open geometries
Dry Scrubbers	Feasibility Study	90 at 1.0 μ[14]	Efficiency falls rapidly with decreasing size	Need to improve submicron capture efficiency
Ceramic Bags	Screening Tests	56-90 for felts using 0.3 μparticles and no filter cake[15]	Long term endurance unproven	Requires media development and life testing
Electrostatic Precipitators	Map of Stable Corona	N/A	Only static tests with clean plates to date	Need to evaluate a flow system to predict efficiency

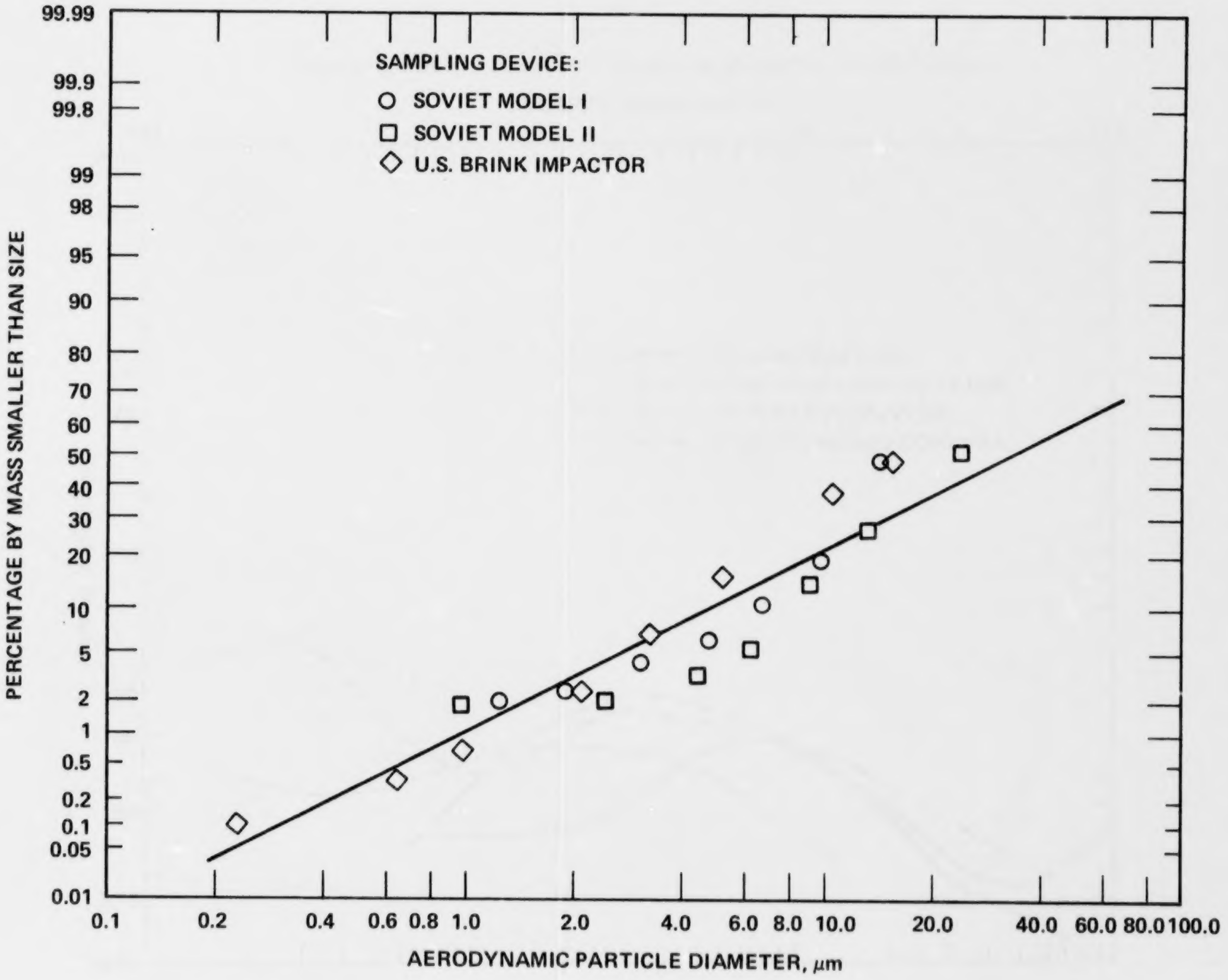

Figure 1. Typical inlet size data for coal-fired power plant particulate.

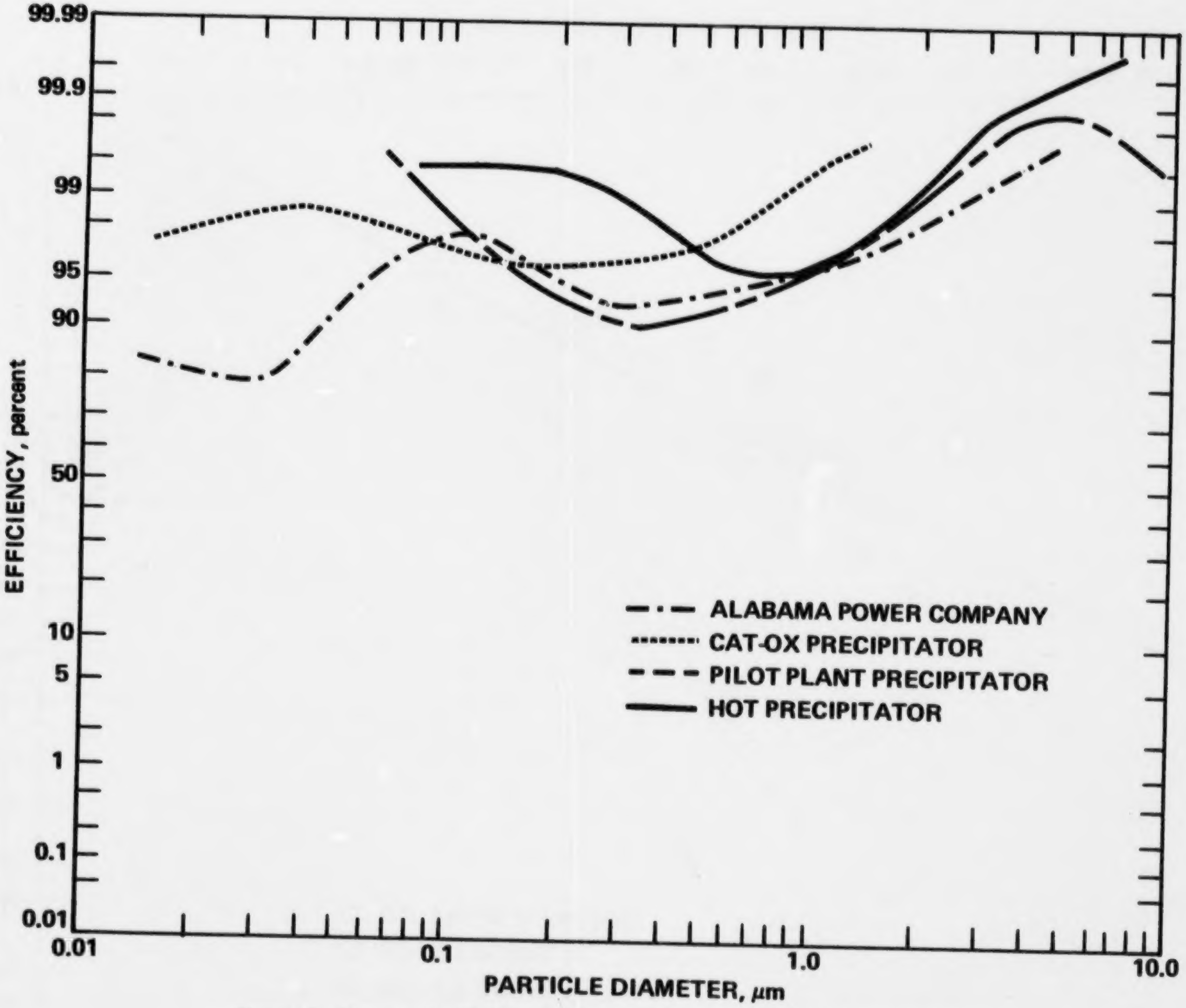

Figure 2. Measured efficiency as a function of particle size for precipitators.

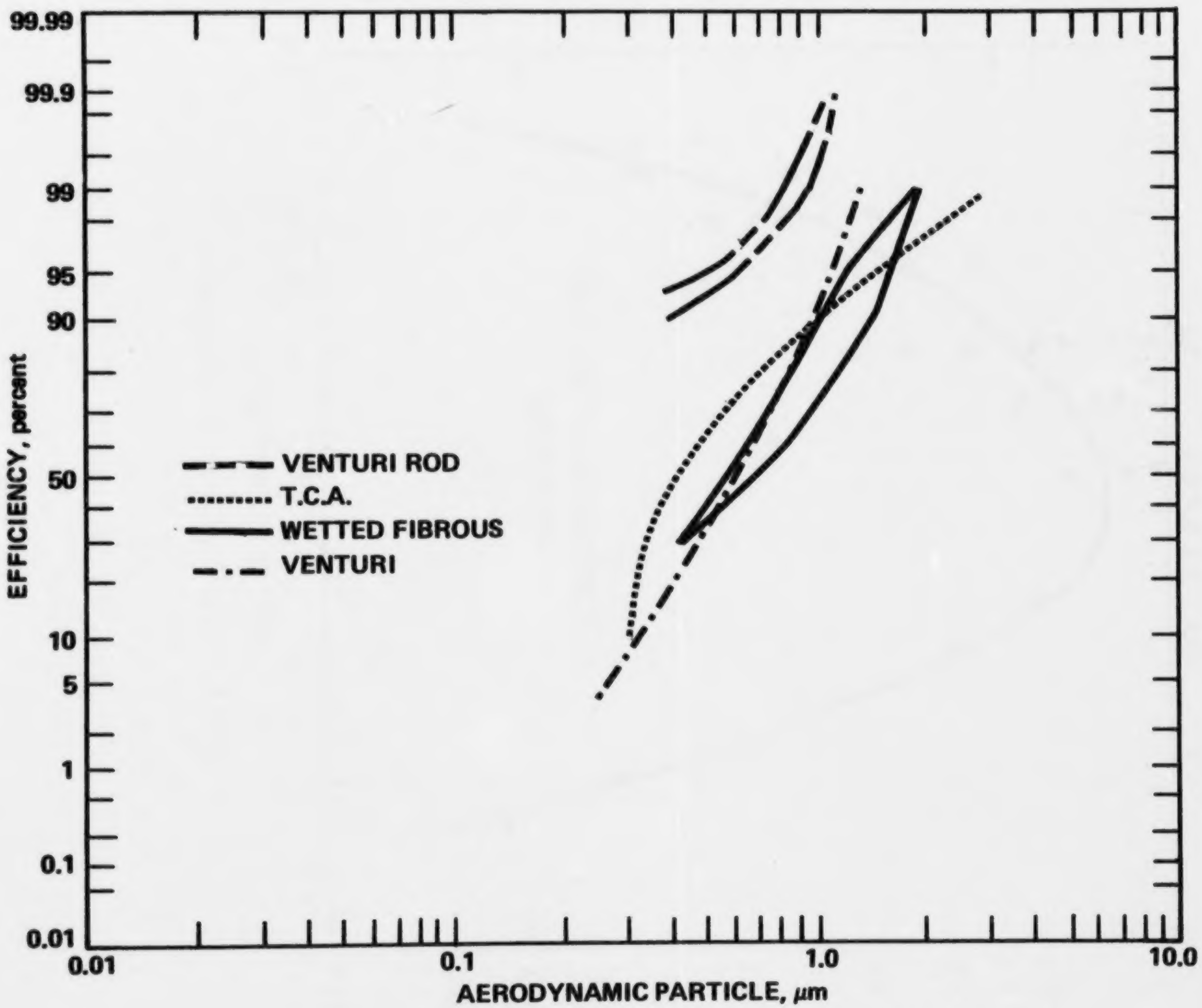

Figure 3. Fractional efficiency versus aerodynamic diameter for scrubbers.

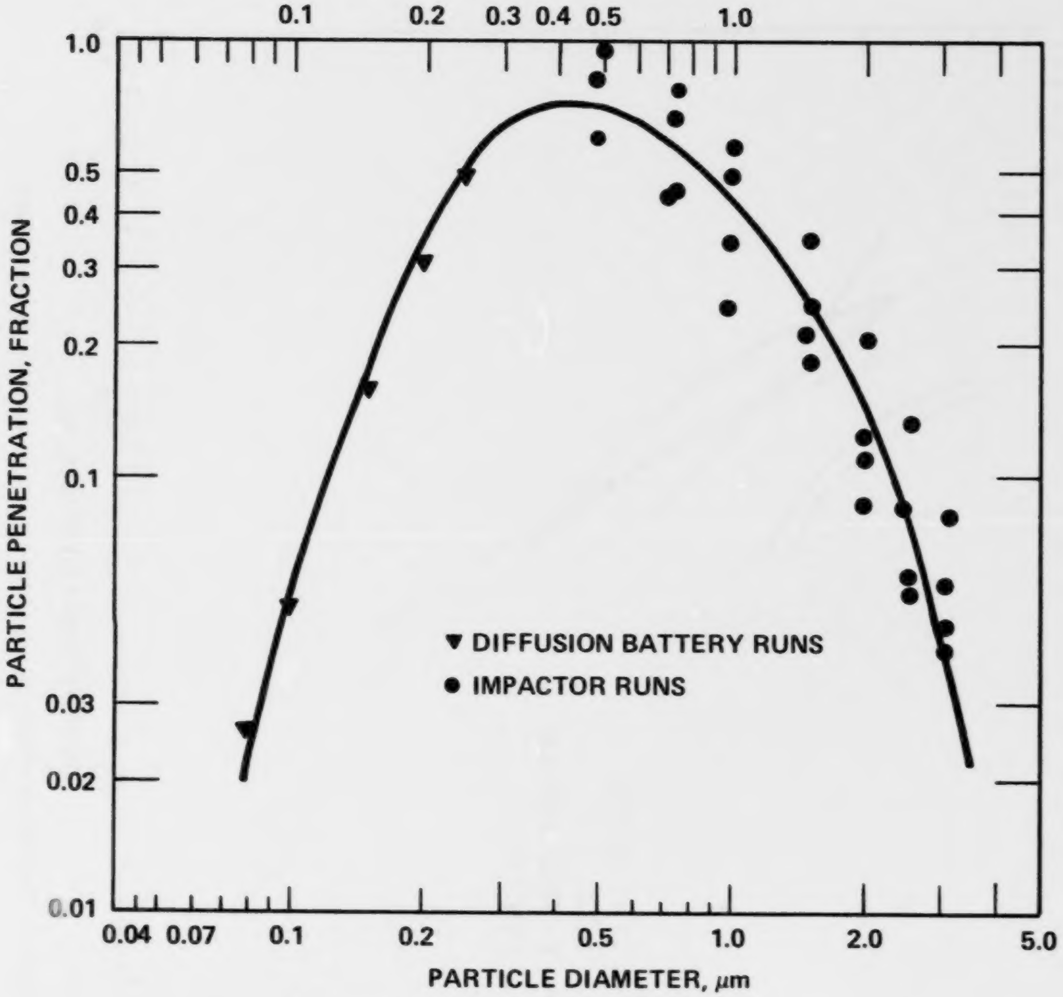

Figure 4. Fractional efficiency of a TCA scrubber.

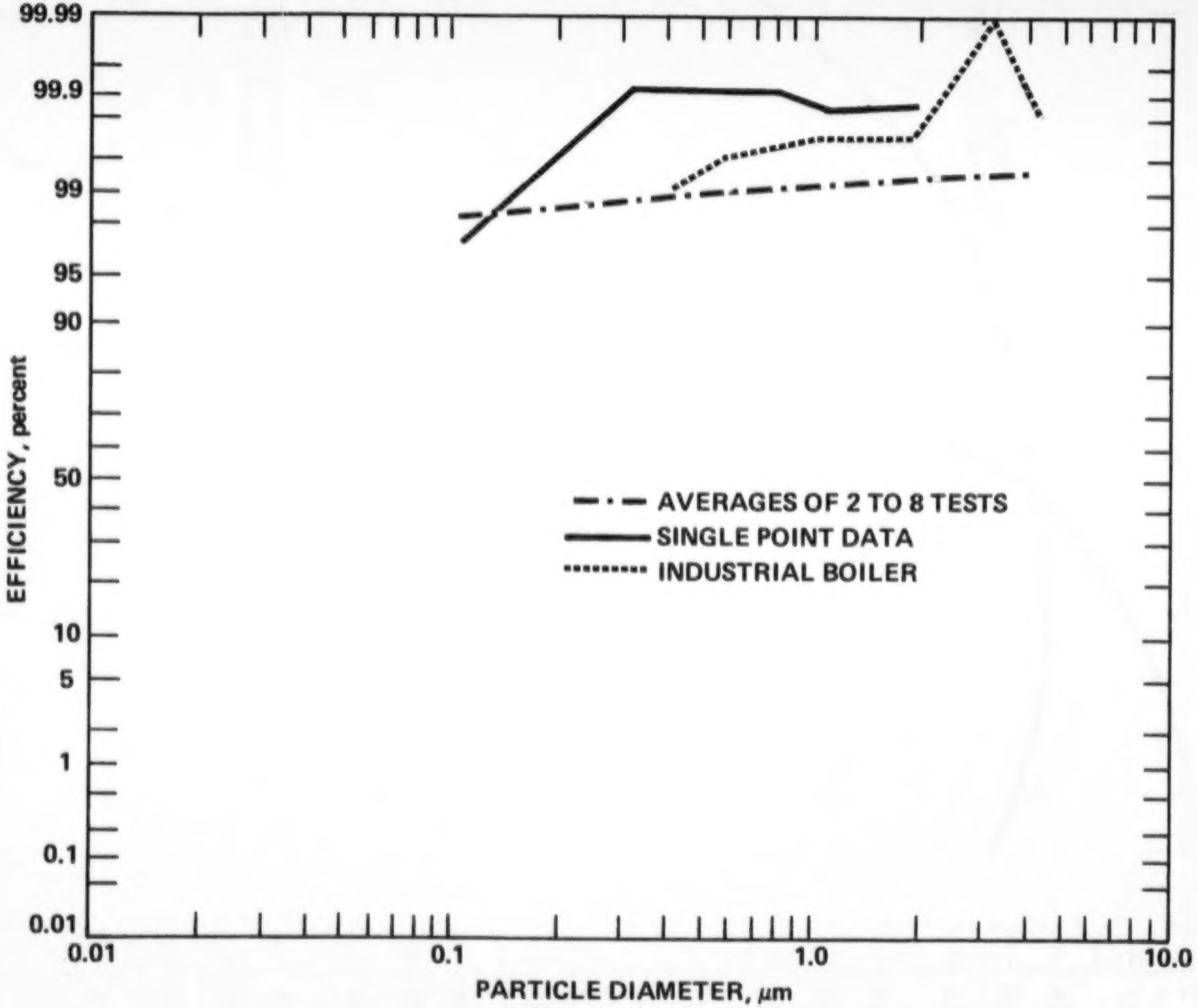

Figure 5. Baghouse performance on utility boilers.

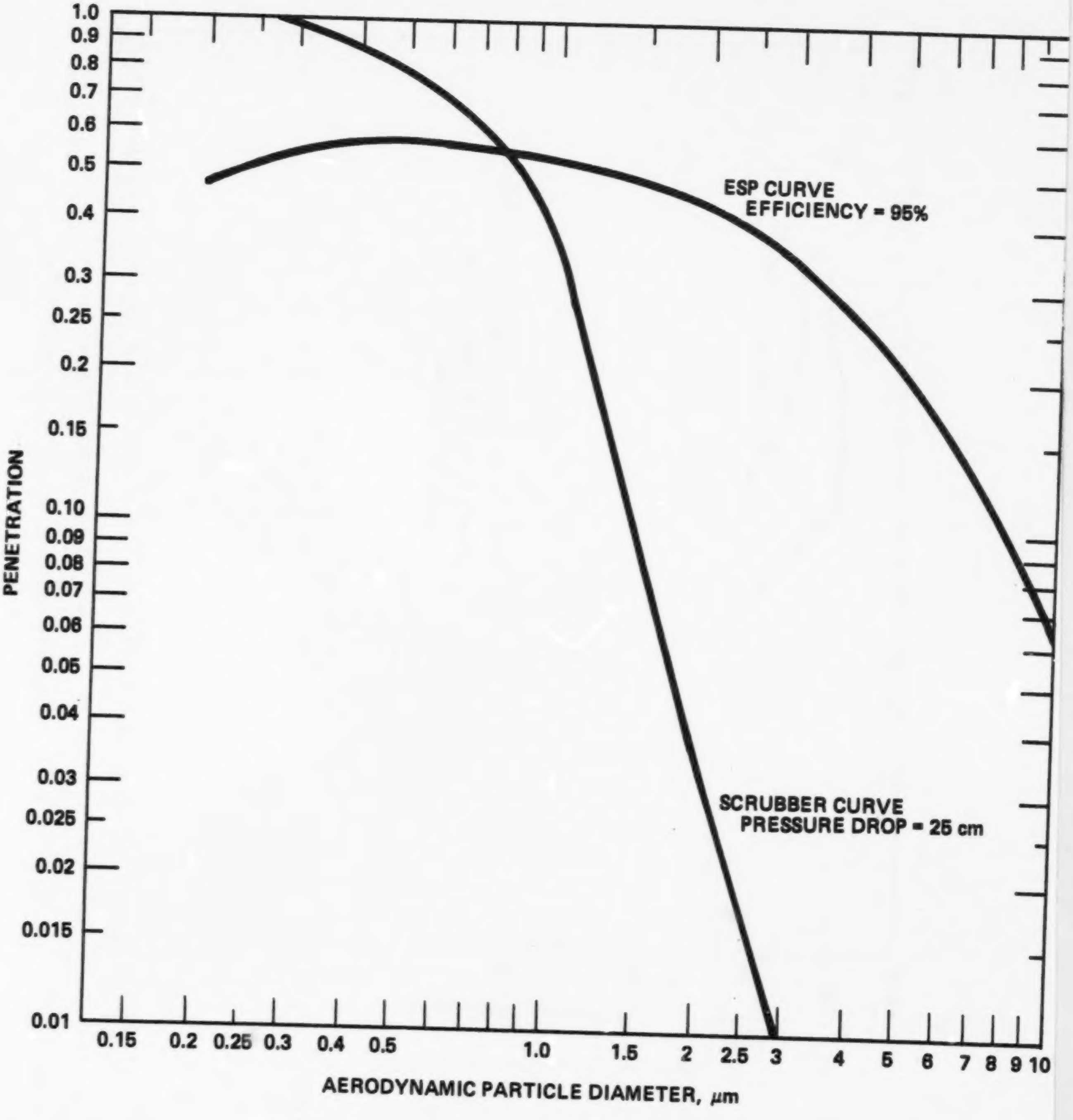

Figure 6. Predicted penetration as a function of particle diameter.

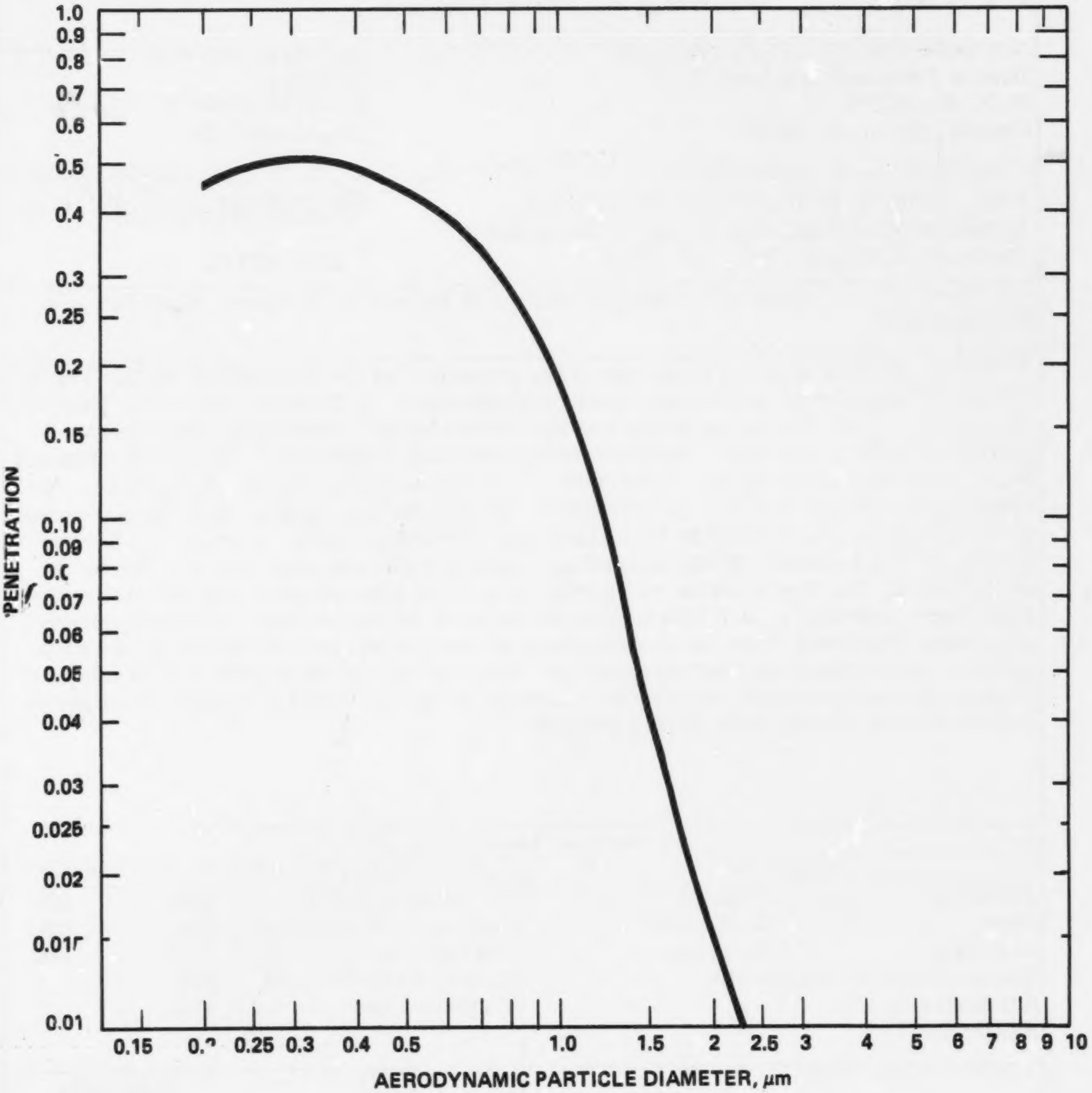

Figure 7. Predicted penetration as a function of particle diameter for ESP and scrubber.